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ON THE

OCCURRENCE OF ARTESIAN AND OTHER UNDERGROUND WATERS

IN

TEXAS, EASTERN NEW MEXICO, AND INDIAN TERRITORY,
WEST OF THE NINETY-SEVENTH MERIDIAN

BY

ON THE OCCURRENCE OF ARTESIAN AND OTHER UNDERGROUND WATERS IN TEXAS, NEW MEXICO, AND INDIAN TERRITORY,

TOGETHER WITH

THE GEOLOGY AND GEOGRAPHY OF THOSE REGIONS,

BY ROBERT THOMAS HILL.

[*From the Final Reports of the Artesian and Underflow Investigations of the Department of Agriculture.*]

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INTRODUCTION.

DEAR SIR: I present herewith my special report upon the underground waters of southern Indian Territory, eastern New Mexico, and the State of Texas.

The region covered is so vast and embraces so many diverse conditions influencing the water supply that I have been able only to treat it most briefly. I feel, however, that in the accompanying pages I have at least outlined the underlying principles of the water supply and pointed out their availability.

The region assigned to the writer for investigation comprised Indian Territory (including Oklahoma), Texas, and New Mexico west of the ninety-seventh meridian and east of the Rocky Mountains, including over 300,000 square miles. This area is such a vast extent that it was impossible to traverse it thoroughly, even in a rapid manner, in the time allotted to the work. The writer, however, has fortunately spent many years in its previous study, but still feels that this report can only be considered, with the exception of the Grand Prairie region, as a preliminary outline of the water conditions.

The area has been so little studied by geographers and geologists that much time had to be devoted to tracing out and classifying its elementary geographic features as a fundamental step to the geological and economic studies dependent thereon. Even the western limit of the investigation, as defined in the organization of the work, is still problematical, for the Rocky Mountains proper cease to be a clearly defined feature south of the thirty-third degree of latitude, and are succeeded by an undefined system of unconnected mountain blocks and plains which have not yet been satisfactorily classified.

The reader of these pages should remember that the regions discussed are radically different in most natural aspects from the older inhabited portion of the United States. It is far more different from New England than is Japan. It has more points in common with Europe than with the great Mississippi Valley. The chalk lands and downs of Texas are more related to France than to the rocks of the adjacent Arkansas and Missouri States. This region of Texas, embracing nearly a third of the whole area of the artesian investigation, has more diverse geologic features than most of the remainder, which necessitates a disproportionate amount of consideration.

The writer has endeavored to give only the laws of the occurrence and distribution of water, leaving to the engineers the discussion of its utilization. Neither is it within the province of this investigation to enter into an elaborate discussion of the minute geologic structure of this immense area, but in order to comprehend its water conditions it is necessary that such features be briefly described.

I have not made this paper a statistical one, for Prof. F. E. Roessler, in his excellent report, has so completely covered that field that it would be useless to do otherwise than to refer my readers to his paper for all possible information in that line.*

I wish to return thanks to the people of the region for their kind and unstinted assistance, and above all to express my gratitude to you for the liberal manner in which you have permitted me to conduct this investigation, and hope the report will be worthy of your approval and useful to the people.

Respectfully,

ROBERT T. HILL,
Assistant Geologist for Texas, New Mexico, and Indian Territory.

Prof. ROBERT HAY,
Chief Geologist, Artesian and Underflow Investigation.

I.

THE OCCURRENCE AND AVAILABILITY OF UNDERGROUND WATER.

No substance is so universally essential and so widely distributed as water, yet the laws of its occurrence beneath the earth's surface are little studied and understood. Although everywhere desired and sought for by man to satisfy the necessities of industry, transportation, and agriculture, the art of search for it has hardly risen above guess work or the superstition of the divining rod.

Water is too abundant in the Eastern States to excite much attention, although the threatened famines of this commodity warn us that the law of its occurrence is worthy of serious scientific investigation even in the humid region.

In the western half of the United States, however, the water question is not only serious but paramount to every other consideration, for there are vast areas as large as all New England, such as the great Llano Estacado, without a single brooklet, river, or permanent pond upon the surface, while there are other areas, aggregating one-tenth of our Union, which, together, do not possess a stream of the volume of the Mohawk or Connecticut and are utterly lacking in the accompaniments of frequent laterals and springs. Great railway lines—for example, the Southern Pacific—are obliged to haul water hundreds of miles for their engines, and have spent millions in not always judicious experiments to obtain an underground supply.

Methods for the utilization of surface waters have been developed, and it only remains to put in practice the knowledge we now possess to save and apply every particle of the available surface water of the land.

The laws of distribution and utilization of underground waters are almost as simple as those controlling surface distribution, but the popular fallacies concerning them are appalling, believed as they are by men of more than ordinary intelligence in other walks of life. The

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* Report on the preliminary investigation to determine the proper location of artesian wells within the area of the ninety-seventh meridian and east of the foothills of the Rocky Mountains, Fifty-first Congress, first session, Ex. Doc. No. 222.

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most current of these erroneous ideas is that all underground water flows in streams "like the circulatory system of the human body," as an intelligent citizen once expressed it. The underground rivers are thought to supply every well and spring, and it is a curious sight to see the water witch or switch fakir plod over a farm with his forked stick trying to locate the "current." In the vast areas between the Rockies and the Mississippi the belief prevails that all the wells are supplied from precipitation upon the mountains, whose waters are supposed to disappear beneath the surface to rise again a thousand miles away along the coastal plain (The Galveston *News*, November 7, 1891, p. 4, top of 4th column), while beneath the vast intervening region is an inexhaustible store of water, waiting for some invention of man to bring it to the surface. This doctrine of the "underflow," as it is called, proved so contagious in Kansas a year ago that whole communities indulged in most exaggerated anticipations of its development.

In view of these facts would it not be well to examine the simple laws controlling the distribution of underground waters:

Surface waters are useful for commerce, industry, and navigation, but for agriculture underground waters are the sole dependence; even when surface water is used for irrigation it must first become earth water before it can become available for the plant roots. For this reason the farmer plows the earth's crust—to increase its capacity to imbibe and transmit water—or drains his field to remove a surplus of moisture.

The source of all underground water is the rainfall, but with few exceptions the underground supply in any region is not proportionate to its rainfall. Of the rain which falls upon the earth's surface, part is evaporated or quickly drained to the sea; the remainder is absorbed by the soil and other rocks.

All the materials composing that portion of the earth's structure visible to human inspection, inappropriately known as the crust, are more or less saturated with water. In arid regions or in times of drouth this may not be apparent or at the immediate surface where the moisture is dried by evaporation, but a fresh excavation—a post hole, a plow furrow, a blast in a quarry, or a newly dug well—will reveal the contained moisture of the earth's crust.

This moisture or earth water may be scarcely visible or may occur in great abundance according to the compactness or porosity of the rocks, the number of fissures, joints, and crevices, and their topographic situation.

If rainfall be long continued the portion of the crust upon which it falls becomes completely saturated. Upon cessation of the rainfall evaporation or drying begins at the surface, thus causing the line of visible moisture to become deeper and deeper. The line of visible moisture is known as the line of saturation or earth water, and its depth in any area decreases with the rainfall and increases with evaporation (temperature and wind movement).

Thus it is that in the eastern part of the United States, where rainfall is excessive and evaporation slow, the line of saturation is usually near the surface, while in the arid regions, like the Llano Estacado and the great basins, it is often several hundred feet below the surface.

Although the belt or portion of the earth's crust between the surface and the line of saturation may be apparently dry, evaporation is constantly going on, the soil serving, like the wick of a lamp, as a medium of capillary attraction, by which vast amounts of moisture are conducted to the surface and evaporated.

The percentage of the water of the earth's crust that escapes by evaporation is not definitely determined, but, owing to the surface exposed, it must far exceed the amount escaping by all other methods The water evaporation is of no direct application to man and is no further considered here.

If the earth's surface were of uniform porosity, temperature, and composition the water it contained would be uniformly distributed through it, as is the water in a well-soaked sponge.

This is not the case, however, for the outer portion of our globe is composed of rocks of much greater porosity and less density than the interior, while the downward percolation of surface water can extend but a short distance, because it encounters the superheated matter of the earth's interior and is either forced back towards the surface as steam (as in the case of geysers and volcanoes) or enters into mineral combinations. Hence we must conclude that the earth water is confined to that portion of the earth's crust between the lines of heated interior and surface evaporation.

Even in this narrow belt the distribution of water is very irregular, for in places, as on the Llano Estacado, holes 300 feet deep can be drilled through soil and rock as dry as powder without reaching water, while in New Orleans water is so near the surface that graves can not be dug for the dead.

The unequal distribution of water in the saturated portion of the earth's crust is due to the difference in porous texture of the different rocks which compose it, their arrangement relative to one another, the amount of rainfall and surface evaporation and the relative altitude above or below the adjacent drainage level.

All rocks imbibe water in proportion varying with their physical structure, a fact which can be demonstrated experimentally by saturating familiar types of rock, sand, brick, chalk, glass, marble, and granite. The glass is similar in water capacity to large areas of volcanic and other igneous rocks, and will absorb no perceptible amount of moisture; marble will drink in a slight quantity; the chalk, sand, and brick will absorb nearly their own weight of water.

The manner in which rocks imbibe water is simple. In most rocks, however compact to the eye, there exists interstices, cavities, and other spaces between the minute particles which compose the mass, in which water may enter and be stored. This is especially true of all sedimentary rocks, which compose ninety-nine one-hundredths of the earth's crust. A fine sandstone, whose grains and intervening spaces may be indistinguishable to the eye, when placed under a microscope resembles a load of cobblestones, in which the spaces occupy as much of the aggregate mass as the solid stones themselves. Into a gallon measure of dry pebbles, varying in size from an egg to a pin head, may be poured half a gallon of water.

Crystalline rocks, as a rule, are more compact and less adapted for the storage and passage of water than sedimentary rocks. Nearly all the minerals which compose them are impervious, as is readily seen in a large crystal of quartz, feldspar, mica, and others. Hence, if a rock is composed of closely woven crystals of massive rocks—quartzite, granite, basalt, lava—its water receiving and transmitting power is minimum. But nearly all sedimentary rocks are composed of minute fragments of other rocks, which have been broken, transported, and arranged by the water according to their size. Most of these fragments are minute crystals or pieces of crystals, and therefore the water conditions of the rock depend upon the size and abundance of spaces between its particles rather than upon its composition.

The different capacities of rocks for holding water have been tabulated by M. De Lerse, of France, and others.

[Proportions of water absorbed by 100 parts stone.]

Great oölite, Bath	31.20
Sandstone, pure quartzose	29.00
Chalk of upper horizon, pure	24.10
Calcareous freestone	18.03
Sandstone (Gres de Beauchamp)	13.15
Sandstone, impure	4.37
Coal shale	2.85
Porphyritic trachyte	3.70
Basalt	0.83
Sibernian slate	0.19
Granite (fine grained)	0.12
Hornblendic granite	0.06

Rocks which have imbibed all the moisture they can contain are in a condition of saturation, and all water in excess of this amount will pass off by aid of gravity, capillary attraction, or evaporation. The excess of water in rocks above the water of saturation is available as the source of springs, wells, and artesian supply.

If experiments with these materials are continued, each rock will be found to possess a different capacity for the transmission of the water which it has imbibed, and the capacity for transmission is entirely distinct from its capacity for imbibition. If the component particles—for instance, the quartz pebbles of a loose conglomerate or the grains of a sandstone—present a smooth impervious surface, water will cohere to the individual surfaces until the entire particle is enveloped in a coat of water. If the interstices are smaller than the average drop of water the resistance of cohesion to the free transmission of water will be greater; hence a chalk or a fine-grained brick will drink in much water but transmit little, while water will pass freely through coarse gravel. Capacity for transmission in variously grained rocks and the accompanying cohesion is similar to that seen in passing water through sieves of different mesh. Thus some chalks with exactly the same capacity for imbibition as sandstones transmit water six hundred times slower.

These materials with radically different capacities for imbibition and transmission of water have been sorted into definite sheets or strata by the water which deposited most of them, so that another important factor in the question of underground water is introduced, the stratification or arrangement of the rocks relative to one another. Earth water percolates downward through a porous stratum until an impervious one is reached (Figs. 1 and 5), while an impervious stratum at the surface will prevent the saturation of a pervious one below.

Stratification performs the important function of controlling the distribution of earth water, of resistance, transmission, and storage.

If the rock stratum is pervious and horizontal it will simply serve as a sponge to hold whatever water it receives until distributed by evaporation or seepage, unless the supply is constantly renewed by rainfall. (See Pl. I, Fig. 1.)

If an impervious sheet is above an outcropping porous stratum it opposes the tendency of water to rise by hydrostatic pressure, and if below, it opposes the force of gravity by preventing the water from percolating to greater depths. If vertical enough from faulting or folding, the strata cut off the horizontal transmission of underground water.

If strata are inclined, water is transmitted by gravity in the direction of inclination, *i. e.*, with the dip; and if the topographic conditions are favorable flowing wells can be obtained at points more or less distant from the outcrop. (See Fig. 2.)

If the strata incline in a direction opposite to the general slope of the country, no matter how favorable the conditions may be, they will furnish no flowing artesian supply, for water can not rise above the height of the receiving area. (Fig. 3.)

If strata are excessively inclined, as in most mountain regions, artesian wells are improbable, if not impossible, over any wide area. In folded, mountainous regions the strata will soon dip below all available boring; hence the generally accepted idea that artesian wells are peculiar to regions of great stratigraphic disturbance is fallacious, except when the condition exists as in Fig. 4. A dip of 1 per cent is hardly visible to the eye, but it will carry a stratum downward 52.8 feet per mile, or 528 feet in 10 miles. A dip of 10 per cent, which is hardly noticeable, will carry a stratum 528 feet in a mile, or 5,280 feet in 10 miles. A dip of 45 degrees will carry a stratum deeper in a mile than any drill has yet penetrated.

It may now be said that the most favorable and usual condition for artesian wells is that of strata inclined slightly at an almost imperceptible angle with the surface slope. This condition prevails in gently sloping basins and not in mountains.

Theoretically, this arrangement affords a large exposure of the receiving stratum for the imbibition of water and underlies an extensive area in which wells can be obtained. All the great artesian well areas of the United States are of this type, that of the Atlantic Gulf coast of Dakota, and of Texas.

The receiving area of an artesian system is the area of outcrop of the water-bearing stratum. Its extent is proportionate to the thickness and inclination of the stratum, and its value for receiving and transmitting water depends upon the area of its outcrop and its porosity. The outcrop may be of any topographic form, but is usually in a valley of stratification which is topographically higher than the outcrop, as in the artesian areas of Texas (See Fig. 1), New Jersey, and elsewhere.

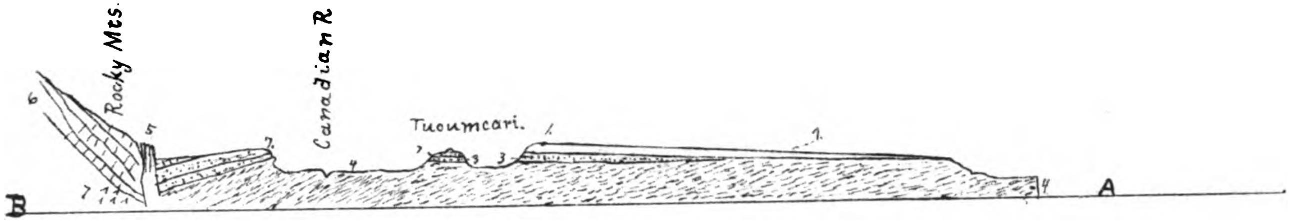
Most sedimentary rocks occur in definite succession, *i. e.* sands overlaid by clays, and by these limestones, representing the deposits laid down at shore, in shallow water and at the nearer shore or moderate depths, respectively; hence when a well is begun in rocks of the limestone group a great volume of water must not be expected until several strata of clays are passed through and the basal sands penetrated.

This sequence or triple succession is not always present, for often the upper limestones and clays have been removed, but the lower members may usually be expected, for it is very exceptional that a clay or chalky limestone is deposited unless preceded by sand.

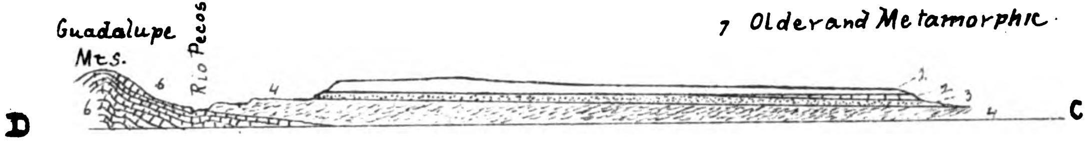
INFLUENCE OF TOPOGRAPHY UPON DISTRIBUTION OF EARTH WATER.

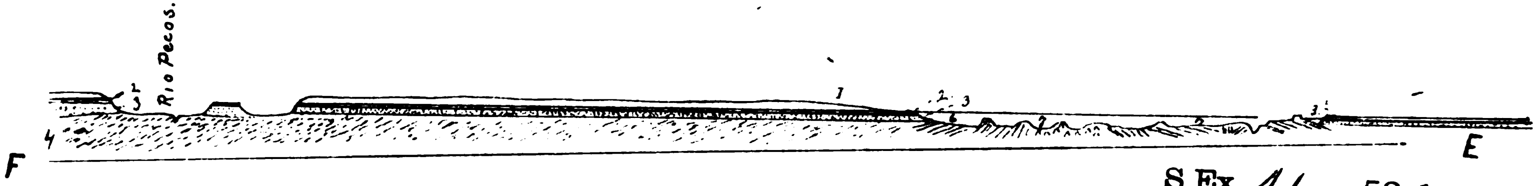
If the surface were a dead level not grooved by river drainage, and were a homogeneous mass, earth water would sink to the line of complete saturation, which would be at a uniform depth, as it is in a flat, undrained field.

But the earth's surface is broken into mountains and plains and the plains are scored by valleys, just as the farmer's flat field is marked by drainage ditches; therefore, through the percolation caused by gravity the line of saturation sinks towards the level of the lowest adjacent drainage valley whose streams are usually fed by the water of saturation escaping at their level. (See Fig. 7.)



1 Llano Estacado Beds.
2. Comanche Limestone.
3. Trinity Sands.
5 Dakota Sands.
4. Red Beds.
6. Carboniferous Limestones.
7 Older and Metamorphic.





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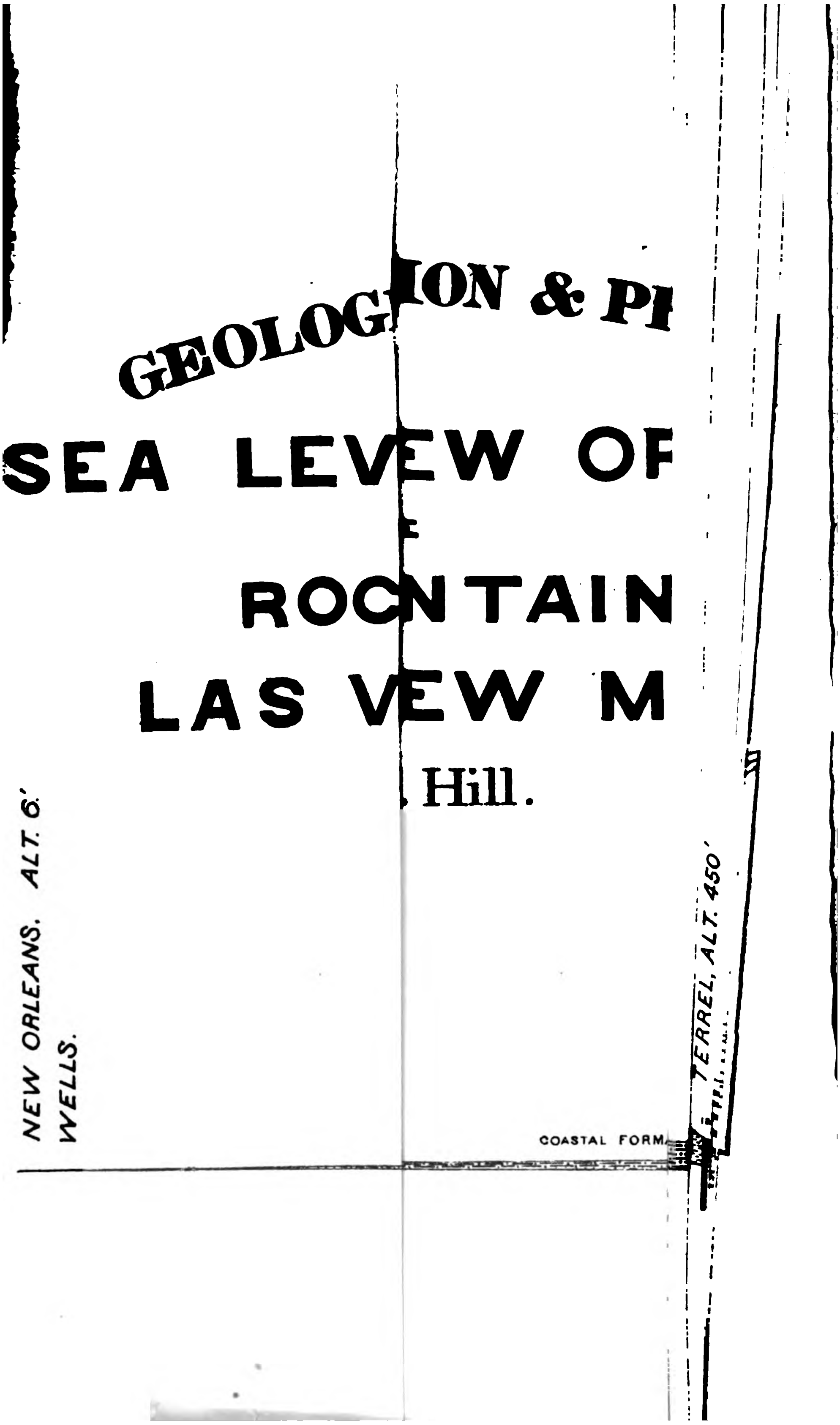
GEOLOGION & PI
SEA LEVEW OF
ROCNTAIN
LAS VEW M
. Hill.
NEW ORLEANS. ALT. 6'
WELLS.
TERREL, ALT. 450'
COASTAL FORM

There are two kinds of valleys in the West—stream valleys and basin valleys. The former are the product of erosion through the rock mass, caused by running streams seeking base level; the latter are the filled-in depressions of vast intermountain areas, like Salt Lake Valley of Utah. The stream valleys reduce the line of saturation of the adjacent regions to their level and carry the earth water to the sea. Basin valleys store the surface water of the adjacent mountains by imbibing and retaining it in their loose, porous strata. (See Fig. 6.)

Topographic irregularities have important bearing upon the success or failure of artesian wells, but not as great an influence as is popularly supposed, for the receiving area of artesian districts is more often a level or valley of stratification than a protuberance.

In mountains of disturbed strata, not horizontal, water level is reduced toward that of the surrounding plain.

Mountains, in general, owe their existence to the compactness and imperviousness of their structure, conditions which render them of secondary importance in a discussion of underground water, since they are quickly drained of their rainfall, except that which becomes crevice water or is retarded by vegetation.

Impervious mountains are often important in concentrating the drainage of a large area upon the porous surface of a basin-shaped plain occupying their center (Fig. 6); they actually double the efficiency of the rainfall for the basins; this fact is of especial value in the southwest, where the country is of impervious mountain and porous basin structure.

In the case of buttes and mesas, which usually consist of horizontal strata, the line of saturation is reduced by gravity towards that of the plain or valley which surrounds them (Fig. 6).

As a rule, the degree of consolidation of an impervious stratum has little bearing upon its function in artesian wells, soft clay shale is practically as impervious as a hard slate; hence the incorrectness of the popular idea in the West that a hard rock must overcap the water-bearing stratum. Consolidation, however, does decrease the transmitting capacity of pervious strata, since this power is produced by pressure which decreases the interstitial spaces of the rocks, or by mineral cement which fills the pores; hence, most of the great water-bearing areas are composed either of loosely cemented or unconsolidated sand.

WATER CONDITIONS MOST FAVORABLE IN THE NEWER (NEOZOIC) FORMATIONS.

The older formations of the earth are more consolidated, metamorphosed, and disturbed than the newer, and hence they occur in but few places in the continuous sheets necessary to great artesian development. The newer rocks (post-Carboniferous) are less consolidated, less disturbed, less metamorphosed, less broken, and therefore are better adapted for imbibition, percolation, and transmission of water. Thus it is that with a few exceptions, the great artesian areas of the world are in the Triassic, Jurassic, Cretaceous, Tertiary, and Quaternary rock sheets, which, as will be shown, play an important part in the region under discussion.

A section from the Gulf coast to the Rocky Mountains, say from New Orleans to Las Vegas, will illustrate the principles I have endeavored to explain (see Profile No. 3). From the coast to the ninety-seventh meridian is a large series of porous sheets of strata inclining with the surface at only a slightly greater angle. This represents, with one or two exceptions, the condition of the entire Atlantic seaboard. These strata constitute the rocks from latest Jurassic to present time and represent a series of ancient coastal deposition plains; nearly everywhere throughout their extent artesian wells are obtained from New Jersey to Texas.

This series rests upon another of older rocks which incline to the westward and against the topograpic slope and outcrops between the ninety-eighth and one hundred and first meridian. No successful artesian wells of large volume have been or are likely to be obtained in this region. A similar negative condition exists in that portion of northeastern New Mexico which I have termed the Las Vegas shoulder; experimental wells of great depth have been drilled without success at Trinidad and Las Vegas.

The principle that greatly disturbed or mountainous areas are not favorable artesian areas is illustrated in the dip of the strata of the Rocky Mountain front, south of the Arkansas, the excessive angle of which almost immediately carries them beyond the reach of man.

The influence of structure and imbibition is shown in the basin plains. (See Fig. 6.) These vast stretches of land in the arid region have been looked upon by the professional geologist as unworthy of experimentation for artesian water, owing to the absence of consolidated strata and the prevailing fallacious idea that the "upturned edges of the adjacent mountain regions were the receiving area of all underground water." Although unconsolidated, the rocks of the basin plains are alternations of porous and impervious beds and hence are valuable artesian areas; by experimentation in boring in properly selected sites considerable water may be obtained. Non-flowing wells have been secured in many of the most unpromising plains, even in Death's Valley; as furnishing water for stock, these wells are very important.

The geological age of strata is of secondary importance in determining the occurrence of underground water, although it is a remarkable fact that with two exceptions the underground waters of our country are obtained from the Neozoic or later formations and from these only where they occur in gently sloping plains or basins, and not as upturned mountain rock.

From these fundamental principles of the occurrence of underground water it is seen that the whole question of distribution is primarily a geological one, and hence a properly constructed geological map would illustrate the underground distribution of water. For instance, a good strata map of the country would show the relative capacity of different subareas for imbibition.

This would be practicable on an extensive scale in the West, especially in the Texas region of the United States, where the formations have great areal development. Approximately the same amount of rain falls upon a great diversity of country, some of which contains great stores of water while others are entirely lacking in this essential. For instance, the mountains of the Trans-Pecos region are mostly composed of hard, impervious rocks—compact limestones, quartzites, and eruptive rocks. Less than 1 per cent of the rain falling upon these rocks is absorbed, except such as finds its way into the structure by cracks and fissures or along lines of contact. As a result of this condition, the water, after every shower, quickly flows down the slopes to the extensive flats which occupy the valleys between the mountain ranges. These flats (see Fig. 6), as well as the entire surface of the Llano Estacado, have a structure entirely different from the adjacent mountains and are for the most part, composed of loose, porous sands and gravels so that every drop of rain that touches their surface is immediately absorbed and does not flow off in streams. This explains the utter absence of running water on the surface of these flats and its abundance stored in the structure beneath. Not only does this basin and plain formation (see Figs. 1 and 6), imbibe all the rain which falls upon its surface, but the great torrents which pour down the mountain sides and cañons disappear immediately upon reaching the plain, being imbibed by its porous structure. The constant streams, also, which flow from the snow-clad peaks or mountain springs, such as the Seven Rivers, the Tularosa, and the numerous lost rivers of New Mexico and Texas, quickly disappear upon reaching the plain.

Immediately underlying the porous beds of the Llano Estacado, which is the latest and capping formation of the area, is an impervious formation consisting of red clays called the Red Beds (Fig. 1). These constitute the surface of a large area of country east of the Llano in Texas, known as the Concho-Abilene country. This formation does not imbibe water freely like the Llano Estacado. Consequently its waters drain off rapidly and its surface is eroded with many dry creek beds or arroyos which contain running water. The rainfall upon these clays quickly flows away to the rivers and from the rivers to the sea, so that the people of eastern Texas often see great rises, usually disastrous overflows, of the red waters which quickly follow rainfall in the Abilene-Concho country.

Again, to the eastward there is a vast area of country known as the Black Prairie and Grand Prairie regions. These are underlaid by chalks, chalky clays, oölites, and chalky marls. All these formations, except the clays, are nearly as porous as sand and imbibe nearly as much water. This region, too, drinks in much of the rainfall, but not as much as the Llano.

If it were possible to view this region of mountains, Llano Estacado, Red Beds, chalks, and sands while a rain was falling uniformly over the whole region, the following diverse phenomena would be seen: First, torrents pouring down the impervious mountain sides to the plains and there disappearing beneath the level surface; second, the level surface of the Llano, void of streams or surface drainage, immediately absorbing the water or temporarily collecting it on the surface in lakes, like liquids in a chemist's filter, until it can pass downward; the impervious Red Bed plains, like the mountains, covered with rills, rivulets, and torrents laden with sediment, which soon flow into the arterial drainage of the Red, the Brazos, or the Colorado. The rainfall upon the chalky regions and the oölites is imbibed almost as quickly as upon the Llano, except in the clay areas.

After the rain ceased an observer would be impressed by the fact that the representative rocks of the different areas exhibited capacities different not only for imbibing water, but also for transmitting it through their structure by percolation, and those rocks which imbibe the least water, like the limestones, porphyries, and quartzites of the Organ, the Guadaloupe, and other trans-Pecos mountains, most slowly transmitted it, so that for days, perhaps months, springs and seeps flow from the crevices and contact plains of the high mountain slopes, keeping alive delicate ferns and rare plants. On the surface of the Llano, except where slight quantities of clay are mixed with sandy loam, in an hour or two there remains little evidence in the dry surface that a shower has fallen, the water having quickly penetrated to depths beneath. The chalks, the oölites, the marls, and the sand exhibit similar phenomena with slight variations. The red beds and clay areas, such as the Black Waxy and Abilene countries, which have much clay in their structures, although imbibing much less water than the other regions, are wet and moldy for many days, according to the amount of clay they contain.

These great differences are due to the different degrees of porosity or percolation of which the rocks are capable.

In conclusion, it is well to consider the application of these principles to obtain underground water in the vast arid regions of the United States and Mexico. First, it is apparent that the best conditions for securing underground water are not in consolidated or mountain rocks, as shown by the futile experiments of the Government well borings under Capt. Pope in 1858 and the numerous failures of the Southern Pacific Road—all of which were drilled with the idea that the earth water came from the mountains. But, on the other hand, the most sterile sandy upland plains, like the great Jornado Muerto, or filled-in river valleys, like that of the Rio Grande, are the most favorable locations for imbibition and storage of underground water.

By taking advantage of this law hundreds of wells, nonflowing it is true, have been obtained upon the greatest of our supposed waterless plains, such as the Llano Estacado and the Franklin-Hueco basin north of El Paso.

The artesian wells throughout the arid regions also demonstrate this principle—especially the wells of the great basin—plains of Utah, Colorado, and California.

The supply of underground water is sufficient to reclaim for agriculture by irrigation only a very small fraction of our desert lands. Yet, by applying these principles, thousands of wells can be obtained upon areas now absolutely waterless, which would be of great value to overland commerce and to herders, and would save large amounts of money now wasted in unprofitable experiments.

II.

GENERAL OUTLINE OF THE TEXAS-NEW MEXICO REGION.

The areas treated in this paper are so vast and differentiated that it is possible only briefly to define them, including as they do portions of most of the conspicuous topographic features of our country accompanied by their diversities of climate, geologic structure, and cultural possibilities. (See Pl. II.)

Topographically the whole region consists of a series of extensive elongated parallel dip plains and plateaus (see Profile 3), extending approximately in a north and south direction, and abruptly terminating at each end by a great mountain system, extending at right angles to them—an arrangement comparable to a wide stairway, in which the steps are represented by the plains and the walls by the inclosing mountains.

This analogy can not be carried too far, however, because great irregularities and depressions will be found in the width and trend of the steps, and the structure of the two mountain systems which represent the inclosing walls is of two entirely different types and periods of architecture; moreover, the escarpments of the steps in most cases face westward or upstairs, while the plains successively dip beneath each other. The wear and tear of time has scarred and disfigured the region, leaving depressions where the drainage or other erosion has crossed the plains and worn the mountain walls.

I have previously shown* the most salient features to consist of the following subdivisions, whose details will be discussed in the succeeding chapters:

1. *The eastern division.*—A series of present and ancient coast deposition plains, consisting of strata of Trinity and later age, cover the eastern half of the State, and collectively form what I call the coastward incline. This includes the coast prairies, the Washington prairies, the eo-lignitic or forest region, the Black prairie, the Grand prairie, and the two cross timbers. The Llano Estacado may be generally classified with this region, but for the present I prefer to treat it separately. This division includes a great variety of surface aspects, and occupies the eastern third of the State of Texas. This can be shown by a line drawn through Montague, Millsap, Stephenville, Comanche, Lampasas, Burnet, and Del Rio. Its total area is about 172,800 square miles. The eastern half of this division is essentially similar to the adjacent lowlands of the Gulf States. The western subdivision or Black and Grand prairies are uniquely Texan and are the chalk region of the United States.

2. The central denuded region, founded upon the great Paleozoic and early Mesozoic (red beds) rock sheets which dip westward, rest unconformably beneath the group of the coastward incline and are exposed by the removal of the latter by erosion or by being upturned in the two great mountain systems which limit the region—the Ouachita on the north and the basin ranges of the trans-Pecos country and northern Mexico on the west. This division is between the eastern division and the great Llano Estacado, and may be classified into three principal subdivisions: (*a*). The country of the Coal Measures, underlaid by the peculiar sands, clays, and limestones of the Carboniferous system of rocks. It includes nearly all the eastern half of the Indian Territory, except along the Red River border, and much of the counties of Jack, Young, Palo, Pinto, Montague, Stephens, Shackelford, Eastland, Erath, Brown, Parker, Coleman, McCulloch, and San Saba. (*b*). The Burnet-Mason country, consisting mostly of granite and metamorphic rocks and older limestones. (*c*). The red bed region, including the peculiar red lands of the Concho, Abilene, Wichita, and Oklahoma regions.

3. *The mountain systems.*—(1) The Ouachita system of Arkansas and Indian Territory is older than the plains of the coastal system, which were laid down against it, and separates the Texas region from the Kansas. (2) The Basin Mountains, west of the Pecos and south of the Rocky Mountains proper (which end near Santa Fe), are composed of the uplifted, folded, and crumpled southward edges of the earlier of these plains, *i. e.*, those found on rocks of Cretaceous age. The Rocky Mountains proper form the northwestern limit of the region and are not discussed in this paper.

4. *Remnental plains of later or allied age to the Rocky Mountain uplift.*—These surround the southern and eastern border and may be

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* The writer has made preliminary definitions of this region in three earlier papers: 1. "The Neozoic Geology of Southwest Arkansas," vol. 2, First Annual Report of State Geologist of Arkansas. Little Rock, 1888. 2. "Classification and Origin of the Chief Geographic Features of the Texas Region," American Geologist, Jan. and Feb., 1890. 3. Bulletin 45, U. S. Geological Survey. "Present Condition of Geologic Knowledge of Texas."

classified as the eastern continuation of the plateau region of the West. They include the Llano Estacado and the Raton Las Vegas plateau and were once continuous with the eastern division, but have been separated by the great denudation which laid bare the central denuded region. These plains occupy 91,200 square miles of northwest Texas and New Mexico.

5. Basin Plains lie between the mountain blocks of the Trans-Pecos region and are continuous in genesis and every physical aspect with the Great Basin region of Utah and Nevada and the so called High Plateau of Mexico. The Pecos and Lower Rio Grande, from Santa Fe, N. Mex., to Brownsville, Tex., marks approximately the eastern border of this great division. The country from Idaho to Tehuantepec is essentially Mexican in physical aspects.

Each of these five grand divisions has its own peculiar features of topography, climate, geologic structure, and water conditions.

III.

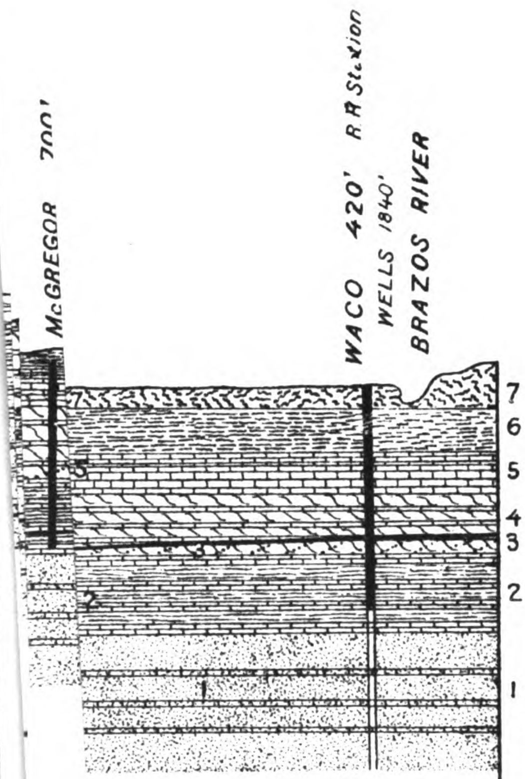
THE ARTESIAN CONDITIONS AND STRUCTURE OF THE EASTERN DIVISION, OR THE COASTWARD INCLINE.

The half of Texas east of a line drawn irregularly from the western edge of Cooke County southward to the southeastern corner of Burnet County, and from there westward to the Trans-Pecos Mountains, presents a remarkably simple arrangement of its stratified rocks, so that its artesian conditions can be easily determined. This vast area embraces a great diversity of country and of accompanying economic conditions. It also has every diversity of climate, from aridity at its southwestern corner to abundant and even excessive rainfall to the eastward. In fact, its only common feature is the favorable inclination of its various strata—sands, chalks, clays, etc.—a most important feature in water conditions.

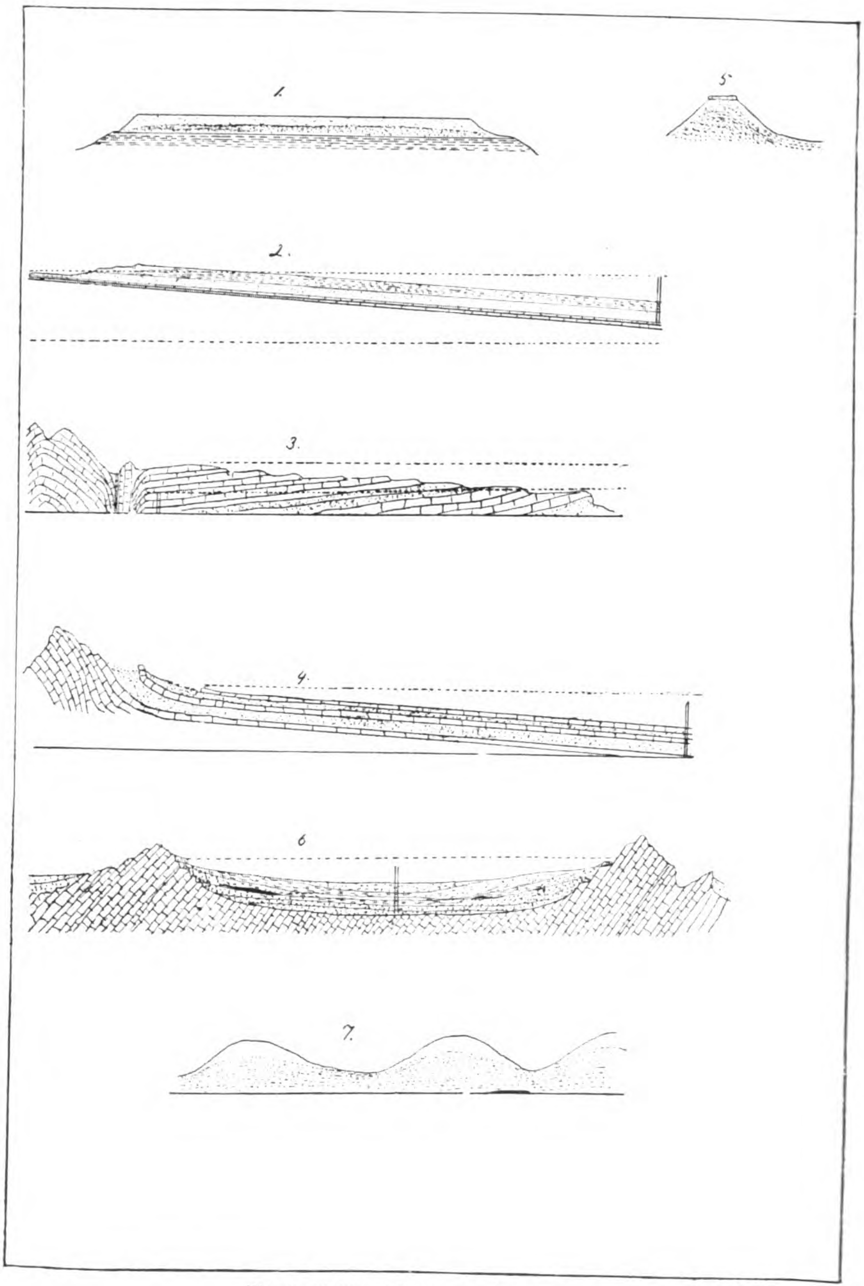
This inclination coastward with the topographic slope is contrary to that of the adjacent Paleozoic and Red Bed areas (see profiles), which incline usually to the west and against the topographic slope. It is also different from the Trans-Pecos Mountains, whose rocks dip at excessive angles.

If one begin at the coast and travel westward across this region he will find that, while constantly ascending above sea level at a slight gradient, he will be descending geologically; that is, he will cross successive belts of country, each with its peculiar soil, rock, and flora, and will see that each of these different aspects is due to the rock sheet upon which the country is founded. (See profiles appended.) The soil and other surface débris, which are the weathering of the underlying rock sheets, are sandy and covered with timber, and wells are abundant if the underlying rock is sandstone; but if it is marly (chalky) clay the soil will be black, sticky, and treeless, and the water poor and scarce.

The outcropping sheets of these various strata, owing to their diverse physical and chemical composition, have weathered into diverse characters of country, forest and prairie, broken or level exactly as the substructure permits. Among those subdivisions of the coastward incline


McGREGOR 700'
WACO 420' R R Station
WELLS 1840'
BRAZOS RIVER

S Ex 41 52 1



Water-bearing Strata and Imbibition.

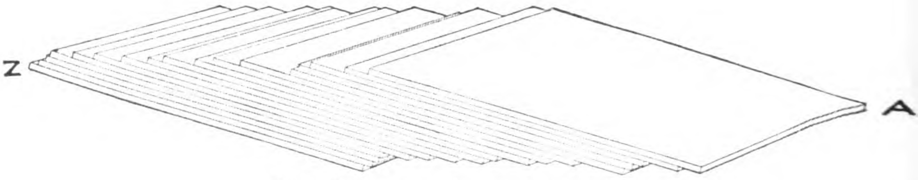


Fig. 8. Illustrating Arrangement of Strata

the country from the coast to the central denuded region. The newer formations are on the southeast, and the older formations successively occupy the country until we arrive at the Paleozoic sandstones and shales of the central region. This is the key to the succession of the various kinds of rocks in the coastward incline.

It will also be seen by beginning with the bottom sheet that the exposed face of each sheet forms an inclined plain of stratification, which is terminated to the eastward or lower edge by an ascending escarpment formed by the edge of the next higher sheet, and upon its western or highest edge by a step-off or descending escarpment formed by its own edge. This inclined plain is known geologically as a dip-plain, as distinguished from a mesa or plateau, in which all the edges are free escarpments. All the parallel belts of country of the coastward incline are dip-plains. The valley where the escarpment meets the dip-plain is known as a valley of stratification; and there are many of these in the region under discussion, the most conspicuous of which is that of the Upper Cross Timbers.

Furthermore, in traveling across these escarpments and dip-plains it will be evident that while the descents of the sudden escarpment faces are great, the gradual ascents of the dip-plains are greater in the aggregate, so that while the last valley of stratification is several hundred or thousand feet lower in the geological series, it is also several hundred feet higher in altitude, thus illustrating the paradox that the receiving areas of artesian well systems are often valleys.

Finally, if by some great strain there should be a great fracture extending across the whole pack of cards as though cut through by a knife, and one side dropped down or raised up, this would be a fault. If this fault were in the direction of the edges of the outcropping cards, it would be a strike fault; and if across the edges or the long direction of the pack, it would be a dip fault. If the dislocation or throw of these faults is great, then it will be seen that the continuity of the transmitting strata will be broken, thus seriously affecting the artesian conditions. If the down-throw be interior-ward, the receiving area may be reduced too low to afford pressure at the point where a well may be desired.

Now, it happens that throughout the vast region of the Grand and Black prairies there are two of these great fault lines—one of each kind—the first of which extends from near Dallas to Del Rio, *via* Waco, Austin, Heliotes, and Uvalde, and is a strike fault which downthrows to the eastward; while the other, which extends from near Marietta, Ind. T., southeastward through Preston, Denison, and south of Paris, Tex., is a dip fault, with its downthrow interiorward, reducing the receiving area below the altitude of most of the Red River counties of Texas, where water would be desired.

This is the simple geological structure of a country embracing the whole eastern half of Texas and southern Indian Territory, an area of over 170,000 square miles, and including all the humid and semihumid regions of the State.

It is the inclination and outcrop of the different strata that produces all the various belts of country as shown in the map accompanying this paper. Especially marked is the relation of timber to structure in this eastern division of our territory. Wherever the country is an open prairie it is underlaid by compact formations with little sand, such as clays and chalks. The coastal prairie, the Fayette prairies, the Black prairie belt, the Eagle Ford prairie, the Grand prairie, and the red beds are all of this class. Wherever the formation is sandy there are forests, as the east Texas pine woods and the lower and upper cross timbers. Each of these different strips of country has a soil radically different from that of the others, for the soil is the surface residuum of the underlying structures.

In addition to being the fundamental cause of all natural and economic differences of the coastward incline, it will be found that these different rock sheets present a very great diversity of water conditions, in accordance with their capacity for imbibition and transmission of moisture. For instance, throughout the great Black prairie region shallow wells are difficult to obtain, owing to the poor water capacity of the clays, while in the sandy regions well water can be secured wherever dug for.

It will also be found that within this system of rock sheets of the coastal incline are several great sheets of sand, which become the receiving areas for vast artesian systems, so that throughout much of the area artesian wells can be obtained, as I shall show more specifically in the following pages. There are at least five groups of artesian water-bearing strata with corresponding artesian areas as follows:

No.	Artesian group.	Receiving area.
1	Coastal wells of Galveston, Houston, Gonzales, etc	Fayette sands.
2	East Texas or timber belt wells, Marshall, Robertson, etc	Eo-lignitic and glaucomite sands.
3	Dallas, Denison, and Pottsboro wells	Lower cross timber sands.
4	The Fort Worth Waco system:	
	Upper division	Paluxy sands.
	Lower division	The Trinity sands and alternating beds.

Each of these systems is of great importance in the economic welfare of the State, and therefore a minute description of them will be attempted in the succeeding pages.

THE EASTERN DIVISION CONTINUED.

THE COAST PRAIRIES.

The coastal portion of the main land of Texas, from the Louisiana to the Mexican border, extends inland from 50 to 100 miles; and consists of a flat usually timberless plain, elevated at its interior margin not over 200 feet above the Gulf. It dips so imperceptibly eastward that it appears to be a landward continuation of the great submarine bench of the Gulf of Mexico. From the deficient drainage, the inconspicuousness of its waterways, and its absolute uniformity of surface, it is evident that this plain is a newly-developed surface feature which has not long been reclaimed from inundation, a fact which is further attested by its want of consolidation, its substructure, and the occurrence among its fossil remains of species still existing in the adjacent waters of the Gulf. Although but a fraction of the total area of the State of Texas, this prairie is an extensive formation, occupying many hundred square miles. It is perhaps the best example of a newly-emerged coastal plain in this country. This feature can be studied along the lines of the Southern Pacific and Texas Central railways, between the Sabine and Hempstead, Tex. Stratigraphically this formation has been but little studied. The absence of timber is due to poor drainage and to the salinity and compactness of the structure. Its evolution and history are

not pertinent to this discussion, but its age is late Quaternary. It
terior margin is rolling and its transition into the next feature is abr
The formation, in itself, is poor in water transmission.

Beneath this plain, however, there are several sheets of artesian w
bearing strata, being the same as those constituting the surface of
next regions inland, and from which Galveston, Houston, and n
other places have secured artesian water. At Houston a great nu
of these wells have been bored, and the city is supplied with t
They are of shallow depth there and increase towards Galveston
at the latter place they have not been so successful as at Housto
securing pure water.

There are no doubt many of these water-bearing strata beneat
Coast Prairie, for there are several thousand feet of porous san
slight intervals, of the Fayette sands and Eocene systems, and f
experimentation will yield magnificent results as yet unattained.

While the portion of the coastal prairie in the longitude of Ho
is abundantly supplied with rainfall it is an interesting fact th
southern end deflects westward into a more arid region, where no
the same artesian conditions exist, and will prove an inestimable
fit to the coastal country known as "southwest" Texas, where
and irrigation are greatly needed. More is said concerning this r
under the head of the Rio Grande embayment.

THE WASHINGTON COUNTY BLACK PRAIRIES.

Immediately westward of the coastal prairies (which it will be re
bered are composed of clay and silts) there is another region
chief characteristic of which is its rich black sandy soil, de
from the disintegration of a friable sandstone, composed most
grains of quartz cemented by calcareous matrix—a great water-be
formation, which dips beneath the coast clays and supplies the art
waters of the Houston-Galveston system.

These prairies have been mapped out by Dr. R. H. Loughridge (s
port on cotton production, tenth census) and the underlying form
described by Roemer, Shumard, and Penrose, the latter having pro
for them the name of Fayette sands.

These sands have a remarkable resemblance to the deposits cons
ing the Llano Estacado and contain also the peculiar opalized
fossil bones, and leaves resembling those of that formation, and
inclined to believe them the same or closer allied terranes, which
extended continuously over the entire region; and I agree with
mard* and Roemer that they are of Miocene or Pliocene age r
than Pleistocene, as has been asserted.

This formation is of great importance in that it is not only a
bearing, but throughout the area of its extent artesian wells oug
be secured from the underlying Eocene sands. The sandy strat
so pervious that they will no doubt supply the whole coastal p

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* Dr. B. F. Shumard, in 1861, announced (see Transactions St. Louis Acade
Science, Vol. 2, pp. 141, 142) "that the discovery in Washington and adjoining
ties of an extensive development of Miocene, deposits of the Mauvaisse Terre,
tion of Nebraska (White River or Loup Fork ?), which have yielded such a wor
profusion of extinct mammalians and chelonians. The Texas strata consists
careous and siliceous sandstone, and white pinkish and grayish siliceous and
reous marls. The calcareous beds are almost wholly composed of finely comm
and water-worn shells, chiefly derived from the destruction of Cretaceous stra
in places abound in fossil bones (and plants) closely allied to Titanotherium, R
eros, Equus, and Crocodilus."

region with water, especially in the more arid southwest portion. Surface wells are also easily obtained in this formation.

As shown upon the map, these prairies extend across the State and occupy large areas of the southern counties immediately interior of the coast prairies.

OTHER ROCK SHEETS ALLIED TO THE COAST CLAYS AND WASHINGTON PRAIRIES.

The geology of the coastal prairies and the Washington prairies is still unraveled, but there is no doubt that each represents a coastal plain rescued in comparatively recent geologic time from the Gulf. Neither the areal extent nor the thickness of these formations has been studied and their interior margins are especially involved in obscurity. Where these margins theoretically ought to be there is evidence of shore lines, in great sheets of gravel, débris, and estuarine deposits of rivers, about which, in order to make a more complete geologic understanding of the region, a few words will be said.

The plateau gravel.—From Arkadelphia, Arkansas, due west to Eagle Town, Indian Territory, twelve miles west of the Arkansas line, and thence southwestward across the State of Texas, *via* Cameron, Austin, San Antonio, and thence around the Rio Grande embayment, there is a great sheet of shore gravel, except where worn away by more recent erosion. In Arkansas this gravel was a beach line along the southern slope of the Ouachitas. In Texas from the Red River to Austin the shore line was the level region of the lignitic Black Prairie and Grand regions. Southwest of San Antonio the shore was the great escarpment of the Edwards plateau, the margin of which is indented with the ancient estuarine valleys filled with gravel. In Northern Mexico great benches of this gravel are found against the Santa Rosa and its kindred mountains, bordering the southern line of the Rio Grande embayment, across which many areas of the gravel are still found preserved from later erosive destruction. This gravel has no important bearing upon the artesian question, because it does not dip beneath an underlying impervious formation; but it is often a valuable source of spring and well waters

The river terraces.—The second phase of interior detrital formations is the great second bottoms or terraces of the older river valleys through the Black and Grand Prairie regions. These are especially well developed in the Red, the Trinity, Little River, the Brazos, the Colorado, and the Rio Grande. They represent estuarine conditions when the Gulf shore was very near the western margin of the coast prairie. These terrace deposits, as seen at Denison, Dallas, Austin, Piedras Negras, and elsewhere are often 100 feet in thickness and form a fair reservoir for the storage of water. Springs are abundant at their contact with their underlying formations.

THE EAST TEXAS OR TIMBERED REGION.

Immediately interior of the Coast and Washington prairies, north of the Colorado, there sets in a region of country entirely different in most of its geologic and cultural aspects. This is the region of the great Atlantic Timber Belt, which marks the interior of the coastal plain from New Jersey to Texas and is well known in eastern Virginia, Maryland, the Carolinas, Georgia, Mississippi, Arkansas, Louisiana, and

Texas, to a slight distance beyond the Colorado. The soil is the same, loose sands, clays, and gravel, with its red and white tints (dependent on the oxidation of the iron), and most of the flowers, trees, and shrubs are the same; so that the traveler in portions of the District of Columbia, Virginia, or other States mentioned need not stretch his imagination to believe that in his surroundings he sees this portion of the Texas region almost as well as if he were there.

This region penetrates the northeastern portion of the State from Arkansas to Louisiana and continues southward across it towards the Rio Grande, but becomes less conspicuous and almost disappears south of the Colorado River, where the climatic conditions are more arid and later formations extend further inland. The western border of the forest belt terminates as abruptly as if stopped by some great topographic barrier, such as a lake or a desert. The abrupt termination of the forest is explained by the radical change in the structure and composition of the underlying formation; the western border coincides with the geographic extent of the pervious soils of the sandy formations and ceases where the compact supercalcareous marls of the Black prairie region begin to occupy the surface. Although mostly concealed by forest, this area of northeastern Texas has an interesting topography. In riding over it, with the view obscured by dense timber, it at first glance appears to be a succession of rounded hills; but a comparison of these with an occasional flat-top drainage divide proves that the whole country is the remnant of a great degraded but still distinguishable plain, of which the valleys are the drainage slopes. The drainage basins, because of the readiness with which the unconsolidated structure yields to erosion, occupy a far greater area than the remnants of the ancient plain in which they are carved. The present level of the rather sluggish streams is from 100 to 200 feet beneath the divides. Their flood plains or bottoms are wide and somewhat unstable. A few feet above these bottoms are the inevitable accompaniments of all the major streams of the southern cotton belt, known as second bottom, often a mile or more in width, while still above and beyond these, marking the edges of the valley, may be one or more benches, usually inconspicuous because of the unstable conditions of the unconsolidated structure and the resemblance between the transported terrace material and that of the underlying beds. The flat divides and wide valleys characterize the whole extent of the region, which, like the entire Atlantic coastal slope, is an ancient plain, whose individuality has nearly been destroyed by erosion in its reduction to the present base level, and by the elevations and subsidences which it underwent in post-Tertiary times. Within this timbered area there is a great diversity of minor topographic and geologic features, similar to those mentioned in my Arkansas report,* the most conspicuous of which are the minor prairies and gravel beds or the overlap or remnant of the interior extension of the Coast and Washington Prairie formations.

The prevalent structure of the lignitic area is alternations of unconsolidated sands and clays of a thousand or more feet in thickness, of the extensive formation known as the Eolignitic or basal Tertiary. These sands contain minute black specks of glauconite or limonite, which from the porosity of the formation quickly undergo oxidation, lixiviation, and segregation, giving the country its colors and producing stratified bands of iron ores.

Although mostly east of the limits of this investigation, it is appropriate to speak a few words concerning the water conditions of this region. The structure, being alternations of loose sand and compact clay, presents every condition for an ample supply of water, especially when we remember the abundant rainfall. This water comes to the surface as mineral springs, many to every square mile, while wells are always obtainable if located with reasonable intelligence. Artesian wells have already been secured in many places from this formation and can be secured throughout its extent. Success is merely a question of topographic locality, for the pressure is not sufficient to cause a flow upon the high divides except along the western margin of the area, but good flowing wells can no doubt be obtained in all the lowlands.

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* See report of geological survey of Arkansas, vol. II, 1888.

THE CRETACEOUS PRAIRIES, INCLUDING THE CROSS TIMBER REGIONS.

The chalky prairies of Texas and Indian Territory are one of the most unique and extensive geographic features of the United States, and entirely different in every scenic and cultural aspect from most of the western plains. They begin immediately west of the great Atlantic timber belt (or Eoliguitic region) in Indian Territory and Texas, and extend westward to the Coal Measures and Red Beds west of the upper Cross Timbers, north of the Colorado River, the Trans-Pecos Mountains, and the basins west of that stream. Northward these prairies are limited by the Ouachita Mountains of Indian Territory. Their southern border is buried beneath the Quaternary débris of the Rio Grande embayment as far as Eagle Pass and the mountains of Mexico.

This region, with its different prairies, each covered by its peculiar vegetation, its sweeping plains, and diverse valleys, its undulating slopes clad with mottes of live oak, its narrow strips of cross timbers, its ragged buttes and mesas, presents a landscape varied, yet possessing as a whole an individuality peculiarly its own. All these features, with their different tints of soil and vegetation and their varied conditions for human habitation, are but the surface aspects of the system of chalky rocks (chalky sands, clays, and limestones) upon which is founded and to which is primarily due every physical quality of the country. It is the great chalky region of the United States.

This prairie region is also by far the most important and fertile portion of the State, and is the seat of its densest population, owing to the great productivity of its calcareous soils, upon which are situated the most important inland cities, such as Paris, Bonham, Denison, Sherman, Gainesville, Fort Worth, Dallas, Waco, Weatherford, Taylor, Belton, Temple, Austin, New Braunfels, San Marcos, San Antonio, Uvalde, and Del Rio.

To these strata the State owes a large part of her agricultural and general prosperity, for they are the foundation of the rich black-waxy and other calcareous soils of those regions. In addition to their agricultural features, they are the most productive source of building material; while adjacent to their line of parting, extending the entire length of the State and dependent upon their stratigraphy, is a remarkable area of natural and artesian wells, as seen at Fort Worth, Austin, Waco, Taylor, San Marcos, and elsewhere.

This country is uniquely Texan as far as the United States are concerned, constituting a distinct geographic region which, in every topographic, economic, and cultural aspect, should not be confused with other portions of our country. It covers an area of over 73,512 miles, or over one-fourth (28.27 per cent) of the total area of Texas; forming a broad belt of fertile territory across the heart of the State, from the Ouachita Mountains of the Indian Territory and Arkansas to the Mountains of northern Mexico—an area larger than the average American State, and equal to the combined area of all the New England States. One-third of this region lies north of the Colorado River, and the remainder to the southwest.

These formations belong to two great rock systems, or series, an upper or Gulf series and a lower or Comanche series of Cretaceous age.

THE MAIN BLACK PRAIRIE REGION.

Immediately interior to the sandy lignitic area, and radically different from it, lies the main Black Prairie, the richest and largest continuous body of agricultural land in Texas, and hence the most important in cultural as well as scientific aspect.

This occupies an elongated area extending the length of the State from the Red River to the Rio Grande. The eastern border of the Black Prairie is approximately the southwestern termination of the great Atlantic timber belt. The Missouri Pacific and the International railroads from Denison to San Antonio, and the Southern Pacific from San Antonio to Del Rio, approximately, mark the western edge. A little south of the center, along the Colorado River from Austin eastward to the Travis County line, near Webberville, the Black Prairie is restricted to its narrowest limits. From this point it widens in both directions until its broadest margins, over 100 miles in width, rest near the Red and (Rio) Grande rivers. The topography of the area was well defined some forty years ago by Dr. Ferdinand Roemer as the "*sanftvelliges Hüegelland*," or "gently undulating regions." Viewed from a distance it is apparently level, but closer inspection shows it to consist of many gentle undulations which differentiate it from the topography of other prairies.

Westward the Black Prairie is succeeded by a region with some superficial resemblance to it, and usually confused with it, which, however, on closer study is found to differ from it in all essential points. This is the Grand or Fort Worth prairie, or "hard limerock region," described elsewhere. The so-called mountains west of Austin are the remains of the Grand Prairie. In general, the Black Prairie region consists of a level plain, imperceptibly sloping to the southeast, varied only by gentle undulations and deep wide drainage valleys, void of precipitate canyons. It is cut through at intervals by larger streams, the valleys of which make indentations into the plain, but not sufficient to destroy the characteristic flatness of its wide divides, remnants of the orginal plain or topographic level which have not been completely scored by the later and more youthful drainage system. The altitude of the plain is between 400 and 600 feet. The surface of most of the Black Prairie region is a deep black clay soil, which when wet becomes excessively tenacious, from which fact it is locally called "black waxy." The soil is rich in lime, which, acting upon the vegetation by complicated chemical changes, causes the black color. The region is exceedingly productive, and nearly every foot of its area is susceptible of a high state of cultivation. Large quantities of cotton, corn, and minor crops are annually raised upon these fertile lands, and if there were facilities for water and proper transportation it would soon be one of the leading farming districts of our country.

With the exception of streams which rise in other regions to the westward, and cut through it, the Black Prairie region has few running water-courses; so that along with its excellent soil it has the drawback that for domestic purposes its inhabitants have mostly depended upon cisterns or ponds, both of which have proved most unhealthful. The reason of this absence of surface waters, as will be shown later, is the great imbibing capacity of its soils and rocks.

This region in Texas is very conspicuously divided into two sections, the larger and more important of which is north of the Colorado, while the other occupies the great embayment of the Rio Grande in Texas and northern Mexico.

The main Black Prairie proper does not appear in Indian Territory. A small area of the Eagle Ford Prairie in the Chickasaw Nation, known as Carriage Point Prairie, north of Denison, has been erroneously classed with it. There are also small spots of it in southwest Arkansas, as described in my previous report on that region. (See Neozoic Geology of southwestern Arkansas; vol. 2, Report of State Geologist. Little Rock, 1888.)

THE NORTHERN DIVISION OF THE BLACK PRAIRIE.

The division of the Black Prairie north of San Antonio is subdivided longitudinally into four parallel strips of country, differing slightly, and distinguishable only by slight differences in topography and in the underlying rocks. The easternmost of these divisions north of the Brazos River is distinguished by the occurrence of sand in its black soil, and occasionally pure belts of sand. Between the Brazos and Colorado rivers, however, the sand is hardly perceptible, while in the southern division, or Rio Grande embayment, it attains great development. Immediately interior of this strip is located the largest and most characteristic belt, which is marked by the stiffest of the black-waxy calcareous clay soils. Upon digging throughout this area, the substructure is found to consist of a light blue marl, called by the residents, "soapstone" and "joint clay," from its jointed and laminated structure. The surface, especially of the high undrained divides, is also accompanied in many places by minute depressions known as "hog wallows," which are produced by the drying, cracking, and disintegrating character of these excessively calcareous clays in poorly-drained places. This, the main portion of the Black Prairie, constitutes fully two-thirds of its total area. The cities of Greenville, Terrell, Corsicana, and Kaufman are situated near the eastern border of the sandy and black waxy strips. Manor, Clarksville, Cooper, Taylor, and Temple are all situated in the main black-waxy belt.

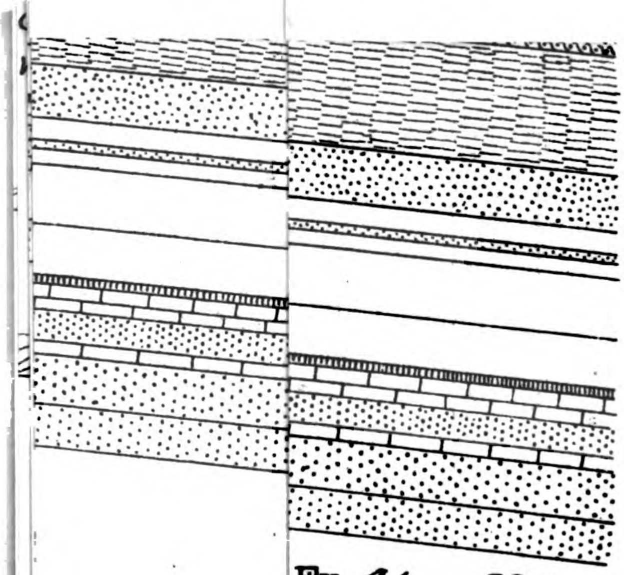
An outcrop of "white rock" or chalky country, forming a narrow strip averaging 2 miles in width, extending from Sherman to the Rio Grande east of Del Rio, succeeds on the west the main black-waxy belt. This chalk belt is marked by a topography more rounded and more deeply incised, but still devoid of the sharper lines of stratification which characterize the Grand Prairie region. It is occasionally marked by clumps of handsome evergreens and oaks.

The western edge of the chalky belt, as seen at Oak Cliffs, near Dallas, and at Sherman, Hillsboro, and other places, is an escarpment overlooking a valley containing the minor Black Prairie and lower Cross Timber strips. This escarpment is continuous except where cut by rivers, from Austin to Denison, 200 miles above the depression occupied by the Cross Timbers to the west. Like every other slight inequality of the earth's surface in Texas, this scarp is locally called "mountains." I propose for this scarp the name of Oak Cliffs or White Rock scarp. This escarpment can be distinguished upon even ordinary maps by the small fringework of minor streams which rise at its summit and drain the dip plain to the eastward, and by the streams deflected by its strike and flowing at its base. The chalk or white rock forming the summit of this scarp is the immediate geologic antecedent of the marly clays underlying the main black waxy area, and the one succeeds the other by easy transitions; hence I classify the white rock as a subdivision of the Black Prairie region. The chalk marks the western border of the main body of the Black Prairie region throughout its extent, but seldom has an areal outcrop of more than 1 or 2 miles in width.

THE EAGLE FORD PRAIRIE REGION.

Immediately west of the Oak Cliff scarp and in its valley there is, especially north of the Colorado, another long, narrow, black waxy strip of country. This is especially conspicuous in Hill, Dallas, Grayson, Collin, McLennan, and Bell counties. (The Sixth ward of Austin is typical of this subdivision of the Black Prairie.) It is intermittent in Travis County, and occurs along an exceedingly narrow north and south line in eastern Williamson, central Bell, and central McLennan counties, the south Bosque marking its extent in the latter county south of the Brazos. North of the last-named stream it begins slightly to widen in area, and continues as a narrow belt, averaging 10 miles in width, northward through eastern Hill, eastern Johnson, western Dallas, western Collin, and western Grayson counties, for 180 miles, to the Red River. This prairie increases in area northward from the Colorado River to Red River, lying west of the White Rock scarp, and east of the Lower Cross Timbers. In Grayson County the belt abruptly turns eastward at a right angle, and runs down the upper slopes of the Red River Valley, through Grayson, Fannin, and Lamar counties, to the eastern edge of Red River; Sherman is situated at its inner angle, and its southern margin is approximately marked by the transcontinental branch of the Texas Pacific Railway, from Sherman to a few miles east of Paris, in Lamar County. The southern border of this eastern Red River area is not marked by an escarpment, but by an inconspicuous fault line. Some of the richest agricultural lands in Texas are located upon this inner Black Prairie region, and its soil is usually fertile in most places.

The portion of the Black Prairie southwest of the Colorado presents many radical differences from the portion north of that river. It deflects westward into a more arid country, and instead of ending with a descending escarpment to the westward it is abruptly terminated by an ascending one—the great eastern escarpment of the Edwards Plateau. Besides these differences the whole region is covered with a thin sheet of sandy and gravelly débris, the remnant of the sea beach which in very late times extended from the southwest corner of Arkansas across the State of Texas via San Antonio to Del Rio. Owing to the presence of this Quaternary débris, and the great development of sand in the beds of the Cretaceous, together with marked differences in the other physical aspects, I have separated this southern region from the Black prairies, and discuss it separately under the caption of the Rio Grande Embayment.



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THE LOWER CROSS TIMBERS.

The western and northern border of the northern division of the Black Prairie region is terminated most abruptly by a narrow strip of timbered sandy land, extending from the Brazos to Red River, and thence down the valley of the latter stream nearly due east to Red River country, known as the Lower Cross Timbers.

Although seldom exceeding 10 miles in width, this remarkable belt of timber is nearly 180 miles in length from south to north, and over 100 miles east and west from its great bend in northwest Grayson County.

The occurrence of this peculiar ribbon of upland timber between two vast stretches of prairie had long been a subject of inquiry until the writer, in 1887, investigated and published* its geology, and showed that the cause of this forest growth was the sandy soil and substructure, which was the outcrop of a rock sheet marking the beginning of the Black Prairie series of rocks.

The Lower Cross Timbers are composed of white sands and sandy clays, oxidized at the surface into ferruginous masses. Viewed from the Oak Cliff or White Rock scarp, looking westward, these timbers appear to occupy a valley, but when observed from the westward, as from Fort Worth or any point on the eastern margin of the Grand Prairie region, they apparently occupy a higher level to the eastward, appearing as low, rounded, wooded, mamillary hills.

The Lower Cross Timbers and the sands in which they grow, for some unknown reason, disappear south of the Brazos. From that stream they extend due northward to the bluff of the Red River, in Grayson County; thence they extend due east down Red River, first touching that stream in eastern Grayson County. From this point the river flows in the line of the timber to Pine Bluff, Lamar County, apparently finding in the soft sands and clays an easy passage way for its winding channel.

By the peculiar fault north of Denison the northern member or narrow east and west belt of the Cross Timbers in that country is split in its length, the northern half appearing 30 miles distant in Indian Territory, extending south of old Fort Washita from the Washita River to the Boggy.

The Lower Cross Timbers are admirably adapted to fruit-growing, and, as will be shown later, play a most important part in the question of artesian water.

To appreciate the water conditions of this vast region it is necessary for the reader to know the sequence of the great rock sheets of the Black Prairie and Lower Cross Timbers that compose it, their water bearing and transmitting capacity, as well as their elementary topography.

GEOLOGICAL SUB-STRUCTURE OF THE BLACK PRAIRIE REGION.

The rock sheets of the Black Prairie region are epitomized in the vertical section before given. The sandy soil of the eastern margin is the outcrop of the upper Arenaceous or Glauconitic division, No. 5 of our section; the main Black Prairie division, the surface of the chalky clays, called Ponderosa marls, No. 4; the White Rock escarpment, the outcrop of the Austin-Dallas chalk, aggregating about 300 feet in thickness, No. 3; the Minor Black Prairie, No. 2 of our section, is also composed of a sheet of clay, somewhat like those of the main division, and hence the similarity of its topography with that of the Lower Cross Timbers, No. 1. These are the rock sheets for which I have chosen the name of Black Prairie series. These sheets with their water capacities will now be described in ascending order, beginning with the lowest beds of the series.

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* (See Geology and Geography of the Cross Timbers of Texas, American Journal of Science, April, 1887.)

THE LOWER CROSS TIMBER BEDS, OR DAKOTA SANDS.

From the Brazos River northward and eastward along the Red River the base of the upper series is composed of a brown, more or less ferruginous, predominantly sandy deposit, resting unconformably upon various horizons of the beds of the Washita division, or top of the Comanche series. These sandy deposits present an infinite variety of conditions of cross-bedding, clay intercalations, lignitic patches, and vary in minuteness of size and angularity of the uncemented particles, characteristic of typical littoral deposits, while occasionally there are found fossiliferous horizons.

The beds are well displayed along the line of the Missouri, Kansas and Texas roads, between Denison and Whitesboro, Denton and Lewisville, and Alvorado and Fort Worth. There are also many bluffs along the Red River where the sand appears to advantage, as Pine Bluff, Sowells Bluff, and others.

These sands differ from those of the Upper Cross Timbers, to be discussed later, in that they contain much more iron and mineral salts.

In the southern and western suburbs of Denison these sands are greatly developed. South of the Brazos River, and at Austin, they are entirely missing, a fact that may be explained in connection with certain changes of level which took place just after they were laid down, exposing them to erosion before the next division was deposited.

The Lower Cross timber strata decompose at the surface into rich sandy soils, which have not been studied minutely. These support a vigorous timber growth, its structure being especially favorable for deep-rooted plants. In age and character these sands are the same as the celebrated Dakota sands of Kansas and Dakota, and equally valuable in relation to the water supply, since they possess great capacity for imbibition. They are the receiving area for the artesian wells at Pottsboro, Dallas, and Midlothian, and when properly understood many other wells will probably be found, as will be discussed later. They increase in thickness toward the north and become more frequently intercalated with clay.

The artesian wells at Dallas have penetrated as yet only about 50 feet of them, but at Denison they are at least 200 feet thick, while at Paris they are still thicker.

The area, extent, and variations of this rock sheet are important factors, since it is the present water-bearing stratum of the Black Prairie region.

The Eagle Ford or Benton clay shales.—These lie to the eastward and immediately above the Lower Cross Timber Sands, from which it is difficult to separate them, and are the foundation of the minor Black Prairie strip.

Beneath the scarp of the White Rock (Austin-Dallas) chalk at Dallas and extending westward through the Mountain Creek country to the Lower Cross Timbers can be seen typical localities of this division, the thickness of which I estimate at 500 feet. In their medial portion they are dark blue and shaly, highly laminated, and occasionally accompanied by gigantic nodular septariæ, locally called turtles, which have often proved a serious obstacle to well drills. The uppermost beds become more calcareous, grading rather sharply into the chalk. There are also occasional bands of thin, impure limestone, which are readily distinguishable from all other cretaceous limestone by their firmness and lamination. Fossil remains of marine animals are also found in these clays, including many well-preserved species, the delicate color and nacre of the shells being as fresh as when the animals inhabited them.

At Austin these beds occur with less thickness, and at one place where Tenth street crosses Shoal Creek they are entirely missing, the chalk resting upon the Shoal Creek limestone. The northwestern part of the city is underlaid by these clays, which are here more calcareous and accompanied by beds of laminated limestone. South of the river, along the International Railroad, they are finely displayed in Bouldin Creek, with the characteristic blue color on fresh exposure. They also appear at San Antonio, near the cement works, and at New Braunfels, Uvalde, and other points. At Waco they form the bluffs of the Bosque, at Prather's farm, and the fish pond. North of Waco they increase in extent and thickness, forming extensive black-waxy areas in Hill, Johnson, Ellis, Dallas, Lamar, Fannin, and Grayson counties, west of the White Rock scarp. This formation is a retaining or impervious rock sheet, overlying the sands, and is not a receiving area for water.

The chief economic value of the minor Black Prairie will always be its magnificent black, calcareous, clayey soil; while some of the chief geological considerations are the ascertainment of means to make this soil more easily handled and less tenacious by devising suitable mixtures, the discovery of road-making material, and the increase of water for agricultural and domestic purposes. Owing to its clay foundation the soil now retains for plant use treble the quantity of moisture of some of its adjacent sandy districts, but surface and flowing water is almost absent.

Fortunately, however, this district is also within the Central Texas artesian area, and an abundant supply of water can always be obtained south of Sherman at a depth of less than 1,500 feet; as has been proved in the course of our investigations. When this fact is fully appreciated the region will be one of the most prosperous in Texas. In the valleys of most of the streams running eastward across the east half of the minor Black Prairie, another flow of artesian water, the same as at Dallas, can be obtained at from 100 to 300 feet. The source of this water is in the Lower Cross Timber sand.

The medial and lower portions of these shales are at places bituminous, as at Austin, Fiskville, Waco, San Antonio, and frequently an appreciable amount of rock oil, appears upon the surface of the waters obtained from them; but so far there have been no indications to justify expectation that this soil occurs in any commercial quantities, the fact being rather against such a conclusion. The clays increase greatly in thickness to the northward, growing gradually less distinguishable from the Cross timber sands in the Red River country, where they can be seen in many places from Bell to Paris. At Dallas they are 525 feet thick.

The Austin-Dallas chalk.—This is the thick stratum of white rock or chalk occurring in the scarp along the western border of the main Black Prairie and separating it from the minor Black Prairie region.

The outcrop of this chalk begins in the southwest corner of Arkansa but is not found in the Indian Territory. It crosses the Red River, b owing to the faulting does not appear westward up the south side of th valley of that stream until reaching Sherman, from which place it de flects southward, passing near McKinney, Dallas, Waxahachie, Hill boro, Waco, Belton, Austin, New Braunfels, San Antonio, and Spoffor Junction, beyond which it bends northward, appearing in the tra mountains in the vicinity of El Paso and New Mexico. It is distinguished above all by its peculiar chalky substructure, and so resembles some of the beds of the underlying Comanche and of the overlyi Upper Cretaceous that until recently they have not been distinguish from them. Upon close examination, however, it is noticeable that th Lower Cretaceous beds of the Grand Prairie are more distinctly stratified and very much harder and generally more crystalline throug pressure, solution, and redeposition of the carbonate of lime in t chalk. The topography of the Austin chalk beds is also of a mild type than that of the Comanche series. Above all, it is distinguishe by its softness and by its entirely different fossil remains. It is als distinguished from the other chalky beds of the upper Cretaceous by its great firmness and by a higher percentage of calcium carbonate.

The rock of this formation is massive, nearly pure, white chalk, usally free from grit, and easily carved with a pocketknife. Under th microscope it exhibits a few calcite crystals, particles of amorpho calcite, and innumerable shells of foraminiferæ. The air-dried indurat surfaces are white, but the saturated subterranean mass has a bluiswhite color. The rock weathers in large conchoidal flakes with a earthy fracture. In composition it varies from 85 to 94 per cent of calcium carbonate, the residue consisting of magnesia, silica, and a sma percentage of ferric oxide, as can be seen from the following analys of random specimens, while the upper Cretaceous beds have only fro 20 to 50 per cent:

	Texas.	Rock comfort
Calcium carbonate	82.512	84.
Silica and insoluble silicates	11.451	9.
Ferric oxide and alumina	3.648	1.
Magnesia	1.189	Trac

The thickness of this chalk is about 300 feet. As far as observed in Texas it averages the same thickness at Austin and Dallas. It is of great uniformity throughout its extent, but there are a few local differences in hardness, which are sometimes due to surface induration and to igneous action, having been converted into marble at Pilot Knob, south of Austin.

In the vicinity of Austin the soft chalky structure is somewhat destroyed by erosion and volcanic disturbances of the vicinity as the deposition of volcanic débris, and excessive jointing and faulting show, but it maintains its pure chalky aspect elsewhere.

A great portion of the former extent of it has been destroyed by erosion, and its western border in central Texas is now receding eastward under the influence of excessive atmospheric decomposition and denudation.

This chalk is the white rock which underlies Fairview Park and most of the city of Austin. Waco is also built upon it; the Lover Leap west of that city being one of the finest chalk bluffs in America

Oak Cliffs, the suburb of Dallas, as well as that city are built upon it, and also Sherman. It imbibes considerable moisture, but transmits none to speak of. Its chief value south of Dallas is that it is a landmark by which artesian wells can be located and their depth predicted with much certainty, as will be shown later.

The Taylor (*or Exogyra ponderosa*) *Marls.*—The eastward continuation of the Austin-Dallas chalk is covered by one of the most extensive and valuable, but least appreciated, geological formations in the United States, a remarkable deposit of chalky clays, aggregating some twelve hundred feet in thickness, according to reported well borings and estimates of the normal strip. In fact these clays are so little known that no popular name has been found for them, and hence they are called from an immense fossil oyster which is found in them. They occupy the whole of the Main Black Prairie region east of the Austin-Dallas chalk, and form the basis of the rich, black, waxy soil. Notwithstanding their areal extent, good outcrops of unaltered structure are seldom seen, owing to their disintegration. Usually they are seen only in ravines, creeks, or fresh diggings. However, at the Blue Bluffs of the Colorado, 6 miles east of Austin, a good exposure is afforded, where these clays can be readily studied and diagnosed. They are of fine consistency, unconsolidated, and apparently unlaminated until exposed to weathering, when their laminated character is developed. They are light blue before atmospheric exposure, but rapidly change into a dull yellow, owing to oxidation of the contained pyrites of iron. Their accessory constituent is lime in a chalky condition, and they make a black calcareous clay soil, characteristic of chalk and chalky clays, whenever their excess of lime comes in contact with vegetation.

Their middle portion is apparently void of all well-preserved fossils, yet impressions are abundant in places. Toward the top, as seen one mile north of Webberville, ten miles east of Austin, they become slightly arenaceous and concretionary and very fossilferous, indicating graduation into the glauconitic division. The fauna of these concretionary clays at Webberville, Corsicana, and elsewhere begins to partake of the character of that of the glauconitic or New Jersey division, and yields an abundance of fossil species.

Although not the top of the Cretaceous system, the Webberville beds are the highest exposures seen along the Colorado River section, for at that place they are overlaid by the lignitic or basal division of the Eocene Tertiary. To the north of Webberville, these sands become more extensive.

The economic value of these chalky clay marls lies in the fact that they are the foundation and source of the rich soil of the main Black Waxy Prairie of Texas, the largest continuous area of residual agricultural soil in the United States, apparently inexhaustible in fertility; for as the farmer plows deeper and deeper he constantly turns to light the fertile marls which renew the vitality.

As before remarked, the water conditions of the formation are very poor and the absence of a healthful domestic water supply has been one of the greatest drawbacks to the region. The very characteristics of the formation that constitute its chief value for agriculture decrease its water conditions. The thick clays can imbibe moisture but slowly, and when saturated retain it, instead of transmitting it, as would a more sandy sheet. The surface wells are difficult to secure and the streams are sluggish and dirty.

Artesian water is the great need of the main Black Prairie region, and to reach even the first water-bearing sand (that of the lower Cross

Timbers) will require the penetration of two great impervious shee the Austin chalk and the Eagle Ford clays, in addition to the depth the ponderosa marls, beneath the desired locality. Upon the extre eastern edge of the outcrop (its thickest portion) two wells, one Terr and the other Thorndale, have penetrated 2,100 and 1,700 feet, r spectively, without reaching the bottom of the Black Prairie series.

The Uppermost or Glauconitic Division.—This division is the upp most continuation of the Ponderosa marls. its chief difference being tha the clays, chalks, and sands become glauconitic as we aseend, and tha there are conspicuous changes in the fossils, which become more plen tiful, the species of fauna partaking of the same characteristics tha distinguish the Cretaceous of the New Jersey and Alabama regions which are of the same formation. This division as it occurs in south west Arkansas has been minutely described in my Arkansas report but its whole detail remains to be developed in Texas, its occurren having been affirmed only in one or two places without specific, detaile study.

The glauconitic or greensand beds are mostly concealed beneath th overlap of the Tertiary and Quaternary beds, throughout their whol extent, from New Jersey to the Rio Grande, and in general it is onl where these have been eroded away that they obtain an outcrop.

They are first seen in two small spots in Bowie County, north of D Kalb Station, upon the Friese place, where they occur beneath th overlapping Tertiaries. This mode of occurrence is geologically know as an "inlier," and there are several more of these glauconitic inliers t the eastward as far as Smith and Anderson counties, all of which ar in the direct line or strike of the Arkansas beds, which they resembl in every detail.

To the westward, however, these beds become more conspicuous, and they attain considerable development in the southern half of the Red River tier of counties as far west as Bonham, whence they deflec southward, constituting the eastern margin of the Black Prairie as fa south as Webberville, on the Colorado.

Commencing in the eastern Red River country, they extend westwar to the sandy beds of the division, outcropping as far west as Ladonia Fannin County, and covering much of Delta, Hunt, Rockwall, and Na varo counties, the brownstone marls outcropping interior of the sand in Kickapoo, Red River country, and south of Paxton, Lamar County

The chalky beds of the glauconitic division (not to be confused wit the Dallas chalk) and the similar chalks (the White Cliffs chalk an sub-chalk of my Arkansas section) outcrop from Clarksville, via Paxto and Honey Grove, nearly to Bonham, but do not persist southward.

In the Rio Grande embayment, southwest of San Antonio, east o Del Rio and the Santa Rosa Mountains of Mexico, these beds agai attain an enormous development, but entirely different in detail fro the north Texas extension, indicating vast difference of condition in th region during the closing epoch of the Cretaceous, and resemble ver much the Fox Hills and Laramie beds of the Northwest.

These beds are well displayed from Eagle Pass to the Webb Count line in Texas, and south of the Sabinos, between Santa Rosa and Tampico, Mexico. They consist mostly of the glauconitic sands alternatin with limestones, clays, and beds of lignitic coal. At Eagle Pass the are fully 700 feet thick, and the whole formation may be even greater. The beds abound in fossil wood and bones, and are of great economic value as coal-producers, the mines at San Felipe, Eagle Pass, and Santa Rosa being of this formation.

THE GRAND PRAIRIE OF TEXAS AND INDIAN TERRITORY.

his geographic feature is characterized throughout by the peculiar estones and clays of the Lower Cretaceous formation, upon which it ounded. It differs from the Black Prairie region proper in nearly ry physical feature. In general it is more elevated, its plateaus are instead of undulating, and its valleys are more precipitate, being ched and terraced through the unequal resistance and varying hards and its alternate stratification. Its soil, except in valleys, is ierally shallow and rocky, while its color tends to yellow and choco- brown, instead of black. The chief difference however is in the dness of the underlying rocks, which are the foundation of all the ove features. These compose a beautiful substructure, whose huneds of feet of white chalk and yellow magnesian layers of alternat- degrees of hardness give to the landscape individual tone and topogphy not found elsewhere in America. The western border of this gion is carved into a rugged scarp accompanied by outliers of terced buttes and mesas. Its interior margin begins at the Arkansas d Indian Territory line at the crossing of Little River, and extends estward 165 miles in the Territory along the southern slope of the uachita Mountains to the west of Marietta, from which point it turns adually due southward across Texas.

The stratification of the central area of the Grand Prairie is almost orizontal, dipping eastward less than 1 per cent, a slightly greater ngle than the topographic slope. In the region of the Edwards Plaeau the dip is less, and approximately corresponds in inclination with he surface of the plateau. In color, composition, and scenic effects hese rocks and their stratification resemble no other region of North America, but they are said by those who have seen both regions to be dentical in appearance with the Cretaceous and Jurassic rocks of eastern France and Switzerland. To this structure and its methods of lisintegration is due the individuality of the topography of the Grand Prairies.

After each season or rainfall the ordinary hue of dry grass is succeeded by varied flowers of indescribable beauty. The soil is usually shallow and is the residuum of the chalky substructure, which is of varying degrees of induration. Its prevalent color is dark chocolate, which readily distinguishes it from all other limestone soils in the State. Although differing in altitude, topography, and structure from the Black Prairie region, this section is not distinguished from it by some people. Owing to the shallowness of the soil and the different conditions of rainfall, but few upland areas of the Grand Prairie are adapted to agriculture, while nearly every acre of the Black Prairie can be utilized. The underlying structure of the Grand Prairie is that of the Comanche series, consisting of alternations of chalky limestones and marls of varying degrees of induration and thickness. These rocks are so much harder than the Upper Cretaceous sediments underlying the Black Prairie region that the region has been appropriately called the hard lime-rock region.

In Texas the eastern margin of this plain, separating it from the Black Prairie region, extends almost southward from Denison via Whitesboro, Denton, Forth Worth (6 miles east), Cleburne, McGregor, Belton, Georgetown, Round Rock, and Austin, to the Colorado, whence it sweeps south and westward, approximately west and north of the line of the International and Great Northern and Southern Pacific railways. From Denison this line is marked by an ascending escarpment (that of the Austin chalk) as far south as Waco, and thence on by the we border of the Lower-Cross Timbers. South of this line the mar the Grand Prairie is marked by a descending escarpment, the Ba fault, overlooking the Black Prairie and the ancient embayment Rio Grande.

The interior border is more jagged and irregular in outline, but where, with the exceptions of the western border of the Stockto sion, is marked by a descending escarpment overlooking the escarp valley of the Trinity Sands (upper cross timbers) or other lower tions upon which it rests. This line is rapidly receding eastward. the destructive erosion, thereby producing the serrated and irre appearance. The edge of the surmounting plateau is from 300 t feet above its base, and everywhere overlooks the lower and diff Paleozoic region, upon which it borders. Owing to innumerable ations of hard and soft layers, it presents a series of alternate be and terraces of stratification, which are of uniform contour and e through long distances, and greatly resemble water made terrac lake shores.

The line of this escarpment is very irregular, forming innumer curves and points. Sometimes it follows the crossing rivers until th the eastern margin of the region is reached, as at the valley of the C rado near Austin. The entire length of this scarp, with its princ meanderings across Texas, can be little less than 2,000 miles. Acc panying this scarp are innumerable circular flat-topped buttes, outlie the main plateau, which have been completely separated from it by mospheric erosion and now fringe the entire margin. These are typ "buttes," the level mesas or tops of which are capped with the ide cal stratum and geological horizon which surmounts the main plat of the Grand Prairie. In symmetry of proportion and horizontal p tion of the composing strata, and in clearness of every detail of st ture, there are no grander or more unique examples of atmosph erosion in our country. Often these buttes, like Double Mountain Stonewall County, are 40 to 100 miles from the main area of the Gr Prairie, and invaluable landmarks in tracing the history of its degr tion. Among the most characteristic and typical buttes are Coma Peak, Hood County; Double Mountains, Johnsons Peak, Round M tain, Santa Anna Mountain, San Saba Peak, Church Mountain, Ca Mountain, Pilot Knob, Williamson County; Two Star Mountain Hamilton and Comanche counties, and Post Mountain, in Bu County.

It seems clear that these escarpments and mesas are the effec erosion, and they illustrate the rapid disintegration the region is un going. If this be true, it requires no stretch of the imagination, e cially when the fragmental patches like Santa Anna and Double Mo tain are considered, to see that but a short time since in geolog times the rocks of the Grand Prairie extended westward to the reg now overlaid by the Staked Plains, completely covering the cen Paleozoic areas and the Red Beds region of the State. Much of erosion took place in the Llano Estacado epoch and converted the del into that formation.

All along the thirty-second parallel from Sweetwater to Pecos it be seen that the western border of the Grand Prairie formation is bur beneath the Llano Estacado formation, without any well marked or fined escarpment. West of the Pecos and southeast into Mexic far as Santa Rosa the western border of the Grand Prairie is broken great mountain uplifts, which have folded, faulted, and tilted at ev angle.

ıus the northwestern margin of the Grand Prairie region in Indian
itory and Texas is being destroyed by erosion. A narrow central
between the Pecos and the Colorado is buried beneath the Llano
ıcado formations, and its southwestern edge is broken by the great
ntain uplifts of that region.

ıe Grand Prairie has many diverse surface features, dependent upon
character of the underlying beds. The eastern margin is usually
posed of treeless dip plain prairies with a black or brownish soil de-
l from the underlying beds of the Washita division. The Caprina
stone and Comanche Peak beds usually outcrop as the cap and es-
ment of the buttes and mesas. At the base of these there is usually
ide valley of fertile chocolate soil, the walnut clays, which are the
f productive soil of the valleys of the region.

he grand prairie can be subdivided into four conspicuous areas: 1,
orthern or Indian Territory division; 2, a central or Fort Worth di-
on, lying between the Red and Colorado rivers; 3, a southwestern or
vards division, lying southwest of the Colorado and east of the Pecos;
Stockton division, lying between the Pecos and Trans Pecos moun-
ıs.

'he Indian Territory division of the Grand Prairie begins at the Ar-
ısas line in the slopes of Little River, where admist the dense forest
the great Atlantic timber belt, with its characteristic flora, small
ts of limestone prairie appear with the rich luxuriant grass and pe-
iar flowers of the Grand Prairie. Going westward the timber belt
omes more and more confined to the alluvial river bottoms, and the
ts of Grand Prairie increase the divides of the central streams flowing
the Red River from the north. These prairies strike east and west,
are true dip plains, inclining due south. The plains of the Kiamitia
tween Kiamitia and Little River), the Goodland prairie (between the
mitia and the Boggy), the Caddo prairie, between the Boggy and
Blue, the Washita prairie, between the Blue and the Washita, and
Marietta prairie, are of this class; that is, they consist of black lands
erlaid by the limestones of the Comanche series (the Denison, Fort
rth, Duck Creek, and Goodland beds in the Indian Territory). These
ns in the Indian Territory are seldom over 5 or 6 miles wide, and
southward beneath the lower cross-timber region in which the Red
er flows, from the east line of Grayson County to Towson.

he interior border is the descending escarpment overlooking the
and narrow timbered Trinity valley (Upper Cross Timber), a nar-
valley extending northward between the plains and the moun-
ıs.

n interesting feature of this Indian Territory division is its low
tude, that being some 300 feet below its corresponding Texas por-
s, owing to its occupying the downthrow of the great northwest
southeast fault extending from Marietta via Preston, Denison, and
s, Tex., for over 50 miles. By this fault the Indian Territory con-
ıation of the Texas region has dropped down, a fact which has a
t important bearing on the artesian question, as will be shown later.
st of this fault the strike of the plain and formations changes from
east and west to north and south; also a most important and inter-
ng fact. The continuity of this narrow strip of the Grand Prairie in
ian Territory has been broken by all the through cutting streams,
ch have wide and deep valleys of the Quaternary terraced, or
ond bottom type.

he Central or Fort Worth division of the Grand Prairie.—This is the
irie region of central Texas, north of the Colorado, lying between

the two Cross Timbers belts of Texas, as far south as they extend (lower or eastern to the Brazos), and west of the Black Prairie reg between the Brazos and the Colorado. The Missouri, Kansas Texas Railway from Denison to Austin almost follows its eastern b der. The valley of the Upper Cross Timbers forms the western mar south to the Brazos, and thence southeast to Comanche County. Fr this point southeast to Travis County the margin of the drain valley of the Colorado forms the line.

From northern Comanche County there extends westward some miles, just north of the thirty-third parallel, a long line of flat-top buttes and mesas, the drainage divide of the Colorado and Brazos r ers and the remnant of the former westward extent of the Llano Es cado.

The central or Fort Worth division of the Grand Prairie is a typ dip plain or a series of dip plains lying along the descending esca ment of the central denuded region on the west and dipping bene the ascending escarpment of the Black Prairie (Austin chalk) and Lo Cross Timbers on the east.

The eastern portion of the prairie is comparatively level, like t Indian Territory division, being underlaid by the Washita beds; b as we go westward it becomes more broken, because erosion has w it down to succeeding lower and lower levels, resulting in some of t most beautiful and characteristic scenery in the country. It consis of wide and fertile valleys, surrounded on all sides by imposing sy metrical buttes of the Comanche Peak type, such as the valleys Hood, Bosque, Erath, Comanche, Hamilton, Bell, Williamson, Cory and Lampasas counties. The buttes and mesas are of white chalk limestone, the Comanche Peak Group of Shumard.

The Southern or Edwards Plateau division of the Grand Prairie.—Th Colorado River cuts a very deep cañon through the Grand Prairie Travis County, separating the Central or Fort Worth Division fro the Southern or Edwards Plateau. The last-mentioned area is th portion of the Grand Prairie south of the Colorado and east of t Pecos, and it differs greatly from the other areas. Its width is grea than its length, and as it lies mostly within the truly arid region it less adapted to agriculture. Its surface is also more uniform, bei composed of hard limestone strata, and is a typical mesa or plateau distinguished from a dip plain, since its surface, except where it joi the Llano Estacado on the north, terminates on all sides by a descen ing escarpment instead of dipping beneath some newer formation, as all the other divisions of the Grand Prairie. In fact, it is but the sout east continuation of the floor of the Great Llano Estacado, from whi the Llano beds have been eroded. Hitherto this division has had specific name, having been usually called "the mountains" from t escarpments which surround it. I now propose for it the name Edwards Plateau, from Edwards County, where it is greatly develope

This plateau is an extensive topographic feature and consists of vast rocky plain of hard limestone, covered by a scrubby growth of me quite, nopal (Opuntia), and prosopis, or false laurel. It is a good gra ing country for sheep, but little adapted to agriculture, except in sm patches of creek bottom, owing to the intense dryness of its rocky so structure.

The downthrow eastward of the great fault, which is the cause of th escarpment and which is visible even as far north as Waco, does no become conspicuous until south of the Colorado-Brazos divide, 10 mile north of Austin. From that point southwest to Del Rio, where it cross

Mexico, it becomes more and more conspicuous as a great escarp-
t line, visible to the westward of the International Railway as far
th as San Antonio, and from that point westward, north of the
thern Pacific Railway, the direction of the portions mentioned of
h of these roads being influenced entirely by it. To this eastward
arpment of the Kerrville Plateau the natives have applied the ap-
priate name of the Balcones.

So little adapted to agriculture is the summit of the Edwards Plateau
t its extent upon the map can almost be traced by the absence of
t-offices and other evidences of population.

he northern border of the plateau is marked by the cañon of the
orado from Austin to Travis Peak and thence by an irregular es-
pment running westward through Gillespie, Mason, and Kimble
nties, where it turns westward through Menard and McCulloch,
ning the boundary of the Llano-Burnet Paleozoic area. It turns
stward and southward through Concho and southern Tom Green
nties, and thence forms the irregular breaks of the Concho River
d is merged into the Llano Estacado in Howard, Martin, and Midland
nties. This is a true escarpment of erosion.

An examination of the map will show that the Edwards plateau
oper east of Pecos occupies nearly the whole of the counties of Pecos,
lwards, Crockett, Schleicher, Valverde, Bandera, and about one half
the counties of Kinney, Uvalde, Bexar, Hays, Comal, Concho, Tom
een, Irion, Upton, and Crane, and a small portion of Travis. In
ton and Midland counties the plateau becomes the prevalent floor
Llano Estacado, beneath the peculiar formation of which it is found
the northward. Here its narrowest width is found. After crossing
s narrow neck for about 50 miles the west escarpment is reached in
ich are the breaks of the Pecos Valley and which continues south-
rd along that stream to the Rio Grande, forming a valley from 500
1,000 feet deep.

The greater part of the summit of the Edwards Plateau, like the
no Estacado, is void of streams. Its eastern margin, however, is
lented by a number of streams which are among the most beautiful
the State of Texas. These streams constitute a natural growth of
ers and usually have enormous cañons in proportion to their volume.
ey are mostly mountainous towards their head waters, but near the
nt of emergence from the Balcones escarpment they flow through
ir own débris in cañons and valleys vastly out of proportion to their
sent volume, which no doubt represent the former deposition level
the Rio Grande embayment. From the coastward border of the Ed-
rds Plateau flow beautiful streams of water. Although of secondary
icultural value in itself, this vast plateau has a most important bear-
upon the water question.

t will be well to observe that there are no sharp topographic or struc-
al barriers between the Edwards Plateau and the Llano Estacado,
l that the difference between them is only in the surface formation,
beds of the latter overlapping the former along the thirty-second
allel. Together they constitute a single vast mesa 500 miles long,
in width, surrounded on all sides by escarpments, indented by the
dwaters of rivers which have their source in the underground drain-
from the basal scarps of this vast mesa. While composed of the
erent foundation strata the Edwards Plateau, topographically and
lrographically, should be considered a portion of the Llano Estacado
enomena. Another interesting fact of the Edwards Plateau is the
ies of ancient volcanic necks along its southeastern margin, from

Austin to Del Rio, to which I have previously given the name o Shumard Knobs.

The major rivers, the Red, Brazos, Colorado, and Rio Grande, hav also deep cut into and almost through the formation underlying th Grand Prairie, and their drainage valleys present the same atmospheri terracing as its western border. In places the river valleys assume th aspect of vertical cañons, as in the Colorado, Pecos, and Rio Grand The depth of these valleys below the level of the plains increase southwestward from 200 to 700 feet.

The Stockton Plateau.—The fourth and last subdivision of the Gran Prairie lies west of the Pecos, east of the Davis-Chisos mountains, an north of the thirty-second parallel. It is practically a continuatio of the Edwards Plateau but is separated from it by the great canon o the Pecos. The northern edge of this area is buried beneath the plain formation, while its southwestern border is faulted and upturned in th mountain blocks of the trans pecos region and northern Mexico. Th area lies almost wholly within Pecos County, a small portion crossin over into Mexico.

For the most part it is a sterile, unwatered district, wholly within th arid region, but much of it can be made available by securing under ground water.

The Altitudes of the Grand Prairie.—The Grand Prairie as a rule slopes coastward and increases in altitude interiorward from the gulf. Its altitude above the sea level is least at the extreme northeast corner (the east end of the Indian Territory division), where it is only 50 feet, and is 2,500 feet along the southwestern edge, where it is broken into mountains. The eastern edge is between 500 and 600 feet in height for 300 miles from its beginning in Indian Territory until it makes the southwestern deflection south of Austin. The western edge varies from 1,000 feet at Red River to 3,000 on the Rio Grande. The gradient or slope of the plain can best be understood by the sections and profiles accompanying this volume. It will be seen that it is 14 feet per mile from Red River to Goodland, in Indian Territory; 13.8 feet per mile from Handley to Weatherford through Fort Worth; 13.3 per mile from Waco to Dublin; 34 feet per mile from Georgetown to Burnet; 28.5 feet per mile from Manchaca to the highest points north of Blanco, and 7.8 feet per mile from the later point across the main E wards Plateau.

From the foregoing data it is evident that the slope of the Grand Prairie averages from its beginning, near the Arkansas-Choctaw line, about 14 feet per mile for 300 miles at the Brazos-Colorado divide it increases to 34 feet per mile. From this point southward the Edwards division shows a steep gradient for a few miles along its eastern border of 28.5 per mile, and upon the summit of the plateau decreases to 8 feet per mile. The ratio of this gradient of the surface to the inclination of the rock sheets is the key to the determination of the artesian possibilities.

The Structure of the Cretaceous Grand Prairies.—All the features described, as well as the water and soils, are the products of the unique geologic structure which underlies the Grand Prairie. This consists of a series of almost horizontal sheets of rock, to which the writer has given the name Comanche series, of different degrees of hardness, endurance, and chemical composition, as well as different capacities for the imbibition and retention of water. It is to the different weathering of these rock sheets, also, that the agricultural soil or rock waste, the variation of forest and the prairie, and other features are due; and hence, e the water conditions can be understood, the sequences of these s and their differences must be understood, although they at first appear to be similar and unimportant.

is system of rock varies in thickness, as a whole, from 500 feet at ortheastern outcrop to 3,000 feet at the southwestern, the series easing 3 feet per mile in thickness to the southward. This system ck sheets can be divided into three conspicuous divisions, which rop in parallel belts along its length, the lowest to the westward the highest to the eastward. They are as follows:

) The Washita or eastern and uppermost division;
) The middle chalky, or Comanche Peak (Fredericksburg) division;
) The Trinity or Basal and western division.

ne Trinity or Basal division may be called the great water-retaining sion. The Trinity sands do not occur on the prairie proper, but in valley of its western escarpment. The Comanche or Fredericksg division is the great escarpment and mesa formation, while the shita division may be understood as the eastern or dip-plain forma-. The Comanche and Washita beds are not water-bearing, but e as impervious retaining strata.

Vith these facts in mind let us examine the beds of the divisions a le more in detail.*

THE TRINITY DIVISION.

This is the great water-receiving formation of Texas, and is of the most importance in the consideration of the artesian question. These nds may be divided into a basal or sandy and an upper or calcareous vision, the Trinity sands proper and the Glen Rose (or alternating ds), respectively.

The Trinity or Upper Cross Timber sands.—While in many places ese vary from the underlying floor in material of composition, they re usually composed of fine white cross-bedded sand, locally known s pack sand, mostly unconsolidated, very porous and calcareous, yet ometimes free from lime. In places there are deposits of small jasper nd quartz pebbles, seldom exceeding a pigeon egg in size, round and vorn, and often cemented by a matrix of iron and lime, sometimes arder than the pebbles. This pebble deposit is of various hues, white, lack, and jasper red, and often remains as a residuum over large areas f the red beds and Carboniferous strata, from which the post-Trinity eds have been denuded, as seen in Taylor, Tom Green, Nolan, Monague, and many other counties of the Abilene and gypsum country nd along the western margin of the Llano Estacado. Silicified wood nd occasional fragments of hard lignite occur, the latter seldom, if ver, in continuous beds or strata, but as if the remnant of some solary log or tree floated out from shore.

These sands, although higher in altitude than the eastern half of the rairie region, usually occur in a great valley of stratification that order coastward by an ascending escarpment, beneath which they ip (see Upper Cross Timbers). Owing to the unconsolidated pulveruent nature of these sands, they are eroded more rapidly than the adjacent carp or the underlying floor. As a result of this rapid denudation, the main area of Trinity exposures north of the Brazos is in a narrow valley, seldom exceeding 10 miles in width, which extends nearly 50 miles irregularly northward from the Brazos to the mountains of Indian Territory, and thence eastward to Murfreesboro, Ark. This valley is bounded coastward in Texas by the escarpment of the more indurated material of the Glen Rose beds, and southward in Indian Territory by the Goodland limestone scarp. The Trinity or Upper Cross Timber Valley is a most marked topographic feature in the Arkansas-Texas region. These sands can be seen in the valley of the Upper Cross Timbers in contact with the underlying Carboniferous and the overlying Glen Rose beds all along the western margin of the Grand Prairie, as at Millsap, Bowie, De Leon, Lampasas, but in places around the immediate perimeter of the Burnet-Llano region. The Paleozoic continent persisted above the Trinity shore line until the Comanche Peak epoch. Fifteen miles south of Burnet, however, in another pre-Trinity topographic valley, now followed by the Colorado River below Smithwick Mills, the lithologic nature of the beds are different. Here they consist of coarser rounded pebbles of Silurian and Carboniferous limestones and Llano schist, as well as quartz from the Burnet granite, and fine cross-bedded sands and shell débris (resembling, as seen at Travis Peak post-office, in the bed of Cow Creek, the Florida coquina). The Trinity beds are there in contact unconformably with hard Carboniferous and Silurian limestones, and contain much débris of the Burnet granite. They also vary in composition and thickness with the irregularities of the floor.

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*The Comanche series has been partially described by the writer and others in everal previous papers, for which see American Journal of Science, April and October, 87; American Geologist, January, February, 1890; Report Geological Survey of rkansas, Vol. 2, 1888; Report Geologist of Texas, 1890; Bulletin of the Geological ociety of America, Vol. 2, 1891.

West of the ninety-eighth meridian the Trinity sands are deposited unconformably upon the various beds of the "Permo-Triassic" or red beds, as seen along the base of the remnantal Cretaceous mesas of the Colorado-Brazos divide, Nolan, Taylor, and Mitchell counties. Where the underlying beds are of unconsolidated material, as in the Red River region of northwestern Texas, the remnantal sands often occur over extensive upland areas, as seen east of Abilene, in Taylor County, and in other places. Some of the sand hills along the western escarpment of the plains are also of this nature. This formation, although of limited areal exposure, has a wide range of occurrence along the interior border of the more calcareous beds of the Comanche series from southwestern Arkansas to New Mexico. It is usually absent along the eastern front of the Rocky Mountains, from Las Vegas, N. Mex., northward, unless the Atlantosaurus beds at Canon, Colo., are synchronous, which is not yet known. A portion of the sands of New Mexico described by Marcou and Stevenson, which occur northeast of Santa Fe and at other points near the intersection of the Pecos River, are probably of this formation and may mark its western border. Upon careful comparison I am also inclined to think the white belt of Tucumcari Mesa, New Mexico, and the escarpments of the adjacent Llano Estacado and Las Vegas Raton plateaus is composed of the Trinity sands. Fragmental areas of this terrane are also seen between the Pecos and the escarpment of the Llano Estacado in southeastern New Mexico, east of Eddy, indicating its extent beneath the Tertiary plains. In southern Kansas the Cheyenne sandstones have been ascribed to this age by Cragin.

South of the Colorado and east of the Pecos the occurrence and extent of the sands are concealed by the overlying limestones; and after many journeys in northern Mexico and southern Texas I have been unable to find the base of the Comanche limestones exposed in these regions, except in the vicinity of Miquihuana and Catone, Mexico.

Water conditions.—The imbibing capacity of the pack sands of the

nity is very great, for nearly every drop of rainfall upon them is
sorbed and transmitted beneath the Grand Prairie, for artesian use.
e thickness of the Trinity sands is variable, but from artesian bor-
s at Waco and Fort Worth I estimate it to be from 300 to 500 feet,
ich together with the known area of the sheet beneath the Grand
airie of thousands of square miles makes a grand storage reservoir,
ich saturated with 25 per cent of its volume of water would be equiv-
nt to billions of gallons. While it is doubtful if artesian flow water
be obtained, as a rule, in the area of outcrop of the Trinity sands,
ere is one well on its eastern margin, Bluff Dale, where there is a
all flow. Abundant nonflowing wells are obtainable everywhere
oughout the region, however, at shallow depths, and if these are
ge and deep enough, they can most probably be used for garden
igation. The northeastern part of the town of Comanche is situated
these sands, and the abundant well water of that place is derived
m them.

The Glen Rose beds.—The basal sands of the Trinity division just
scribed are succeeded in continuous depositions by a group of strata
ich are of great importance to the water question, owing to their
eat capacity for water. These are composed of soft yellow magnesian
ssiliferous beds, sandy at base, alternating in dimension layers with
exceedingly fine argillaceous sand, with occasional layers of porous,
alky, and magnesian limestones and are often oölitic in structure. At
ount Bonnel, west of Austin, this oölitic structure is seen in many of
e layers of indurated stones and marls, while nodules and geodes of
eautiful anhydrite, calcite, and strontianite crystals are quite abundant
nd are of value as a means of identifying the terrane.

There are in these beds many layers of dimension stone of almost
dentical lithologic character with that of the celebrated Caen quarries
f France, so largely imported into our northern seaports. This stone
s extensively quarried at Weatherford, Granbury, Belton, Oatman-
ville, Kerville, and other places, and will no doubt some day occupy an
important position in the resources of our country.

The unequal weathering of the hard and soft layers produces in the
eroded topography a beautiful bench and terrace effect, so much re-
sembling ancient shore lines along the western escarpment of the
Grand Prairie, where it overlooks the Trinity Valley and the lower
Paleozoic beds from which it has been eroded, that earlier geologists
have often confused these features with shore topography. On fresh
fracture these rocks are usually white or of an intense orange or yel-
low color, but weather into a dull gray.

The Glen Rose beds north of the Colorado-Brazos divide are exposed
along a narrow area occurring as a prairie strip in the heart of the
upper Cross Timbers. Their first appearance northward is in the
western part of Wise County, and they increase in area southward in
Parker, Hood, Erath, and Comanche counties. They constitute much
of Hood, Somerville, Comanche, Lampasas, Ball, Travis, and Burnet
counties, occurring in the slopes of the rivers.

These beds do not outcrop in Indian Territory, owing to the overlap
of later deposits, but appear in Arkansas from Ultima Thule eastward
to Murfreesboro; the limestone layers described in my report on Ar-
kansas under the general classification of the Trinity sands belong to
this terrane. In the counties of southwestern Texas, between the
Pecos and the Colorado and south of the Burnet-Llano Paleozoic
region, these rocks attain a great thickness and form the mass of the

Edwards plateau. The Guadalupe, Comal, Nueces, Frio, Medina, and Devils rivers have their origin in these alternating beds.

They also constitute the prairie spots in the upper Cross Timbers, between Weatherford and Millsap, on the Texas Pacific road, and all the slopes of the valleys, except Comanche Peak, around Gransbury and Somerville. The hills (except the highest summits) around Lampasas, and in Travis County, west of Austin, are familiar examples of these beds. They are beautifully stratified and their rich yellow tints make unique landscapes.*

In the southern area these beds are surmounted by the Walnut clays or Exogyra Texana beds, which are assumed to be the base of the true Cretaceous. North of the Lampasas they are overlaid by the Paluxy sands, an arenaceous, water-bearing terrane of great economic importance hitherto unrecognized and undifferentiated from the Trinity division.

The total area of the outcrop of these beds is large, and they are an important factor in the water question, for they imbibe water for the artesian supply almost as readily as the sands. Upon Mount Bonnel and elsewhere it is noted that immediately after a rainfall the oölitic marls of these beds so completely imbibe the moisture that the roads are made firmer and better for travel instead of becoming muddy.

The thickness of the beds between Comanche Peak and Paluxy is 300 feet, while along the Colorado Cañon they average about 425 feet, as seen in sections accurately measured under my direction by Messrs. Taff and Drake.

It is important to note that these water-bearing beds are merely an upward continuation of the Trinity Sands, enormously increasing the whole thickness and areal extent of the artesian area. The lower Cross Timber sands, on the other hand, are capped directly by very impervious clays, which decrease the downward passage of moisture into them.

The Paluxy sands.—North of the Colorado-Brazos divide the alternating beds of the Trinity division are succeeded by a sheet of fine white pack sand, oxidizing red at the surface, about 100 feet in thickness, closely resembling the Trinity sands and often mistaken for them. They outcrop along the eastern edge of the Brazos Valley, in Parker and Hood, and also in Erath, Comanche, Coryell, and Bosque counties. South of the Colorado-Brazos divide they disappear, the Comanche Peak beds resting directly upon the Glen Rose beds. These beds are especially conspicuous southwest of Granbury, forming the timbered upland of that region, along the line of railroad between Granbury and Stephenville and around the base of Comanche Peak.

The Paluxy sands, which are so called from the town and creek of that name in Somerville County, can first be separated from the Trinity sands in Wise County at a point between Decatur and Alvord. At Decatur the beds are well developed. In general character they are somewhat similar to the Trinity sands, but there are differences. The Paluxy sands have none of the fine pebbles which characterize the base of the Trinity and are more calcareous and argillaceous in places, while those of the Trinity are more ferruginous.

At Decatur the Paluxy sands contain layers of honeycomb bed and very argillaceous limestone. The gradation from the Paluxy to the overlying and underlying beds at Decatur is also rather gradual. At Comanche Peak the sands form the plain upon which the butte stands, making a belt of forest region surrounding its base. Here the beds have a thickness of about 100 feet, and of a character similar to that at Decatur. West and south of Comanche Peak they occupy a considerable area, while they extend many miles down the Brazos, finally disappearing at Bluff Mills near Kimball where they make the shoals over which the river runs. Jonesboro, Coryell County, is situated directly on the outcrop of these sands, and the Lanham road northward from the town crosses it several times. A few miles north of Jonesboro the sands have a thickness of only about 15 feet, showing a decrease to the south. The transition from the Paluxy sands to the underlying beds s a little more gradual, for which reason these sands are placed in the Comanche Peak division.

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* In the mountains of northern Mexico the beds again appear through the intervening Tertiary plain as a part of the Santa Rosa and Arboles ranges, but they are metamorphosed into a hard blue limestone, which has been mistaken by some for Silurian.

The sand is stratified and occasionally cross bedded, and there are local hardenings. The color varies from gray to yellowish, and the amount of ferrugination which is here found is variable. The sand is also marked by the growth of forest timber, largely post oak, though smaller growths, as sumac, also occur. The sands probably extend for a considerable distance down the Leon Valley, although it is difficult to determine their exact extent on account of confusion with the drift of the Leon River, composed of this débris. The sands appear only in scattered spots further toward the south. Thus, east of Burnet, on the Mahomet road, they appear as occasional areas of reddish sandy lands, bearing a growth of post oak. Sometimes these localities are very small and may be seen on one side of a slight valley of erosion, but not on the other at the same level. Elsewhere, however, they have a very considable and unmistakable outcrop, as, for instance, near the junction of Northern and Russell forks of San Gabriel River.

To the northward the Paluxy sands increase in development, overlapping interiorward the Glen Rose and the Trinity beds and abutting against the mountain area in Indian Territory from a point west of Ardmore eastward to the Arkansas line, where they occupy the escarpment valley of the basal Comanche Peak beds of Preston limestone. They also appear at Preston Bluff near Denison. These sands, which the writer has hitherto classed with the Trinity and which may yet prove to be inseparable from them, have been traced by him during the past year from the Arkansas line westward. At no place in Indian Territory east of the ninety-seventh meridian do the Glen Rose beds outcrop, and it is my opinion that they still remain concealed there by this uneroded overlap of the Paluxy sands, for the alternating beds are again exposed beneath them in Arkansas.

The absence of these sands south of the Colorado-Brazos divide can best be explained on the hypothesis that the near shore sedimentation diminished from the mainland area to the southward and by the existence of the buried pre-Trinity and the pre-Paluxy topographic protuberance of carboniferous limestone, which persisted above the Trinity waters in the Burnet area until the Comanche Peak epoch, and extends from northern Burnet and Llano counties eastward into Lampasas County, and then divides the country into a northern embayment and a southern open sea. The presence of this ridge is shown by the difference of level in the pre Comanche floor, as exposed by the erosion of the Comanche sediments at Lampasas and Burnet, and by the horizontal deposition of the latter upon its unequal altitudes. This is especially well shown in the profile from Burnet to Smithwick-Mills postoffice, the Carboniferous floor being revealed in unconformable contact with the Trinity at all altitudes from 650 to 1,200 feet.

The Paluxy sands are also a water bearing sheet, and increase th thickness of the water-bearing group (the Trinity, Glen Rose, and Palux beds). It is this sand which supplies the first water struck in th Waco and Fort Worth wells. South of the San Gabriel it can not b expected.

The impervious beds of the Comanche Peak and Washita divisions.—The strata succeeding the Paluxy sands are mostly impervious or r taining layers, by aid of which the water in the previously describe formations is confined under pressure to greater depths. These sheet in ascending order are as follows:

1. *The Gryphaea rock and Walnut clays.*—The Paluxy sands are every where succeeded throughout their extent by a remarkable stratum of oysters (Gryhpaea pitcheri) occurring sometimes in solid masses from 10 to 5 feet thick, and in some places imbedded in a calcareous matrix. Thi sheet is sometimes underlain and overlain by yellow laminated marl containing a flat oyster (Exogyra texana, Roemer). Hence the Gryphaea rock and Exogyra clays must be discussed as one sheet. Th yellow clays also contain occasional flags of hard, crystalline limestone composed largely of shells of Exogyra texana. For these the name o Walnut clay is proposed, after their characteristic occurrence at Walnut, Bosque County.

At Comanche Peak this great oyster bed and the clays encircle th base of the butte, forming a well-marked bench around the mountain Below them are the timbered Paluxy sands. The shells are more or les loosely cemented, and form one of the most unique rock sheets in ou country. This stratum, which is an invaluable guide to well borers extends from the Trinity to the Lampasas and is beautifully exposed i the counties of Parker, Wise, Hood, Erath, Comanche, Hamilton, Coryell, Bell, and Lampasas, forming a foundation for the Walnut clays whose exposure is coincident with it.

The Walnut clays, which are alternating strata of thin limestone flag and yellow clay marls, are accompanied by inconceivable numbers o the flat ear shaped oyster (*Exogyra texana*, Roemer). These cla weather into exceedingly fertile chocolate-colored soil, forming the chie agricultural valleys of the Grand Prairie division. In extent these bed coincide with the Gryphaea breccia. North of the Lampasas they ar separated from the Glen Rose beds by the Paluxy sands. South of tha river they rest directly upon these sands, and constitute a prominen topographic bench or plain near the summit of the buttes, as seen wes of Austin in Travis County.

2. *The Comanche Peak chalk.*—Overlying the walnut clays and succeeding them rather abruptly is more chalky rock sheet, for which D Shumard proposed the name of the Comanche Peak beds. This chalk i the formation constituting the slope of the mountain (butte) betwee its base of walnut clays and the cap rock. The chalk is hard but readil disintegrates and usually occurs as the slope or escarpment of the butte and mesas. It is exceedingly fossiliferous and its numerous and characteristic species are given in my check list. The thickness of this be averages about 100 feet in central Texas, but it thins rapidly to th northward and thickens to the southward. The beds grade upwar into the Caprina limestone, from which it is differentiated, however, b displaying more regular and frequent lines of stratification and by it crumbling nature.

The beds are sometimes covered with growth of rather thin scrubby oaks, but usually they are bare, and can be readily distinguished b their whitish slopes, as seen near Ben Brook west of Fort Worth. Th soil is thin or absent, and the angular fragments of the weathering rocks make up the surface. Frequently, however, there are large areas over which the Comanche Peak horizon extends as the surface of the formation.

The Caprina limestone—Topographically this is an important factor in Texas, since its superior hardness and resistance have preserved it as the capstone of the innumerable round "mountains" (buttes), mesas, and plateaus of the central portions of the State, where it forms great rocky plains of resistance to denudation. So perfectly does this limestone find expression in the topography that its extent can readily be traced by the highest contours of the topographic maps of the United States Geological Survey of Coryell, Bell, and other counties. It may be said to be the determining factor in the topography of the region. All the buttes or so-called mountains north of the Colorado are capped by it; the great scarps which often run for miles overlooking the prairies to the west represent the same stream; the walls of the cañons which many of the streams have cut are almost invariably composed of the Caprina limestone. South of the Colorado it is also the cap sheet of the great Edwards plateau.

This rock sheet is the direct continuatian of the Comanche Peak chalk, only the limestone is harder and more persistent, and the fossils less numerous and characterized by the occurrence of a few peculiar forms.

At Comanche Peak the limestone is between 30 and 40 feet thick, and though it increases southward it does not change greatly. It can correctly be called an indurated chalk. It is more or less stratified, although usually a great massive bed from top to bottom. Some parts are harder than others and so make up a curved outline to the bluffs; others are materially softer and frequently are eroded away, leaving either honeycombed cavities or shelves under the overhanging hard layers. In places it contains beds of beautiful flint nodules.

Concerning the distribution of the Caprina limestone it may be said that its outcrop covers an aggregate area larger than the State of Massachusetts. In northwestern Texas the Double Mountains of Stonewall County are capped by the Caprina; as are also Comanche Peak, and all the buttes, and the high bluffs marking the cañon of the Brazos from Bluff Mills near Kimball far down the river, the buttes and mesas about Walnut and Iredell and toward the south, those about Meridian, Jonesboro, and Valley Mills, and the Jehosaphat plateau of Travis County and western Williamson county. It is seen in grand bluffs along the Nolan River at Blum, and in some of the smaller streams near Fort Graham; it outcrops in the creek at Belton, and makes up the whole surface of the broad mesa, extending thence westward for several miles to the point where it makes the cap of the great bluff facing westward—a magnificent illustration of the relations of uniform and gentle dip together with comparative hardness to the process of erosion. It caps the buttes as far west as Kempner and southward toward Florence, where it makes again the level surface of the mesa. Pilot Knob, north of Liberty Hill, Williamson County, and many of the buttes high up the Colorado about Anderson Mills are capped by it. The Caprina terrane is usually covered with a thick growth of scrubby oaks and smaller trees, especially where the outcrop is not of large area and the rock comes near the surface. In places there are broad fertile prairies upon its outcrop, as about Pancake, Bagdad, and Turnersville.

It has been stated that the Caprina is uniform throughout. In the southern portion of its area there is an exception to this rule and it might be divided into an upper or flinty member and a lower or cha subdivision. The flints appear in the vicinity of Meridian, but only a few fragments; they increase very rapidly southward, being seen grand development about Belton. In the northern part of the reg they are comparatively large, oval flattened nodules, usually of bl flint. These occur throughout the larger part of the region studied, tending southward at least as far as Pilot Knob, a few miles north Liberty Hill, and thence on to the Rio Grande, constituting the sum of Edwards Plateau. It is doubtful if the downward extension of t rock sheet be as hard as the surface outcrop, for all the chalky ro of Texas harden or set upon surface exposure, through their hydrau properties, and hence in drilling wells this rock sheet will not prove hard at the surface. This formation thins to the northeast and toget with the underlying Comanche Peak chalk and Walnut clays is rep sented only by a thin stratum in Indian Territory, which is known the Goodland limestone. (After the town of Goodland in Indian T ritory.)

4. *The Washita or Indian Territory Division.*—In order to appreci this division in the region of its greatest development, we must trans our attention from central Texas to southern Indian Territory and t Red River, north of Denison. In this region the sands (Paluxy or Tr ity) occupy an escarpment valley against the southern flank of t mountains from north of Marietta to Murfreesboro, Ark. These a surmounted on the south by an escarpment of fine white limeston which I have called the Goodland limestone, and although only 20 fe in thickness it is shown to be the Comanche Peak group. Southwar and above this begins a group of strata to which I have given the nam of the Washita division of the Comanche series.

This division has its prevalent and characteristic development in nort ern Choctaw and Chicksaw nations of Indian Territory and in norther Texas, in Grayson, Cooke, and Tarrant counties, where it is the predon inant formation. It extends southward to the Rio Grande at Del Ri but becomes greatly changed in lithologic character, assuming a mo calcarous aspect and decreasing in thickness, except a portion of its u permost beds (the Denison beds), which for water purposes should t classified with the lower cross timbers sands. These Washita beds a mostly impervious, and nonwater-bearing. It is important to be ab to recognize them, however, for by them the depth and flow can be e timated with certainty.

5. *The Denison beds.*—The Fort Worth semichalky beds are overla in the Red River district by a series of shallower deposits of laminat arenaceous clays (the Arietina clays), at the base grading upward in the sandy clays and occasional limestones, the chalky element of all t underlying Comanche series having finally disappeared. The detail these beds as seen with slight variation in Grayson, Cooke, and Dent counties and in Indian Territory presents a threefold division. At t base they are composed of a blue marly clay weathering brown, wi occasional layers of immense rounded fissile indurations, generally brow in color. Above these the beds are more sandy and ferruginous, oxydi ing into ironstone and almost indistinguishable from adjacent Dako sandstones, but separated from them by the uppermost bed of impu yellow limestone which underlies Main street at Denison.

The foregoing rock sheets are those which control the artesian co ditions of the central Texas region, and with them in mind the pos bility and probability of water can be discussed intelligently. Befo doing this, however, a word or two is necessary as to the variation

er of the extensive deposits. From a study of four parallel sec-
ısed upon actual measurements at intervals from 100 to 200 miles,
ng from Indian Territory southward to the Rio Grande, the fol-
deductions may be made:

'hese beds were laid down against the Ouachita Mountain system
an Territory and over all the preëxisting area of Texas, except
mountain areas of the Oregon and Guadalupe mountains.

'he more littoral, or water bearing, terranes of the Dakota,
, and Paluxy beds and the Denison beds increase in thickness and
apacity character to the northward and diminish to the south-

'he chalky terranes, as the Comanche Peak, and Caprina
ne and the Glen Rose beds, thin out to the northeast; they increase
usly in thickness southward, in which direction the open sea pre-
In boring artesian wells these different thicknesses play an im-
part.

POGRAPHIC EXPRESSION OF THE COMANCHE TERRANES.

ng described the stratigraphic units which compose the Comanche
s, attention is invited to the unique topographic forms which char-
them, and to the extensive erosion which they record. Primarily
tem, as a whole, may be conceived as a great sheet of strata dipping
ard from the interior at an average rate of 20 feet per mile,
ing in strike with the shore line against which they were depos-
This strike is first due east and west from Murfreesboro, Ark.,
ietta, Ind. T., a distance of 300 miles. From the latter point
ittle westward of southward to San Antonio, Tex., whence it
s westward to the Trans-Pecos Mountains. The area of this
s marked by two long and simple fault lines, which produce the
pographic inequalities due to disturbance. The first of these be-
the angle of the intercepting strike in Indian Territory and Texas,
tends northwestward and southeastward, through a point north
ison, Tex., for over 50 miles. The downthrow is 600 feet to
rthward, and Red River flows along the line of this fault for 20
r more. The second great fault extends from near Dallas to Del
ex., passing by Austin, New Braunfels, and Uvalde, with increas-
wnthrow as we proceed westward.

e have been at least three great epochs in the destruction and
ation of this ancient Comanche rock sheet. The western bor-
s faulted and much elevated during the northern Mexican, Trans-
and southern New Mexican mountain-making epoch, for its rocks
nto their disturbed structure in increasing quantity southward.
diments of the great Llano Estacado epoch which constitute the
Estacado formation, are largely composed of Comanche débris.
ensive was the denudation and erosion of this little-appreciated
ne epoch that the western two-thirds of the Comanche series was
led, and entered into the composition of these lake deposits.

t this great denudation of the Comanche series took place since
ocene is further demonstrated, first, by the utter absence of
che débris in the sandy littoral beds of the latter formation; the
eveling of the Eocene time did not cut down to the Comanche se-
secondly, by the fact that the Comanche débris again enters into
sition of the post Eocene formations of the coastal region, of prob-
ynchronous age with the Llano Estacado epoch.

second epoch of destruction of the Comanche series by denuda-

tion thus far recognized was in late Quaternary time, when the
coast coincided with the present western border of the coast prai
By this process the water-bearing sands were removed from a large
and the older strata exposed.

By this erosion and degradation by far the greater part of this m
nificent series has been eliminated, and what now remains, altho
covering an immense area of country, is only a remnant of the prev
extent of these water-bearing rocks.

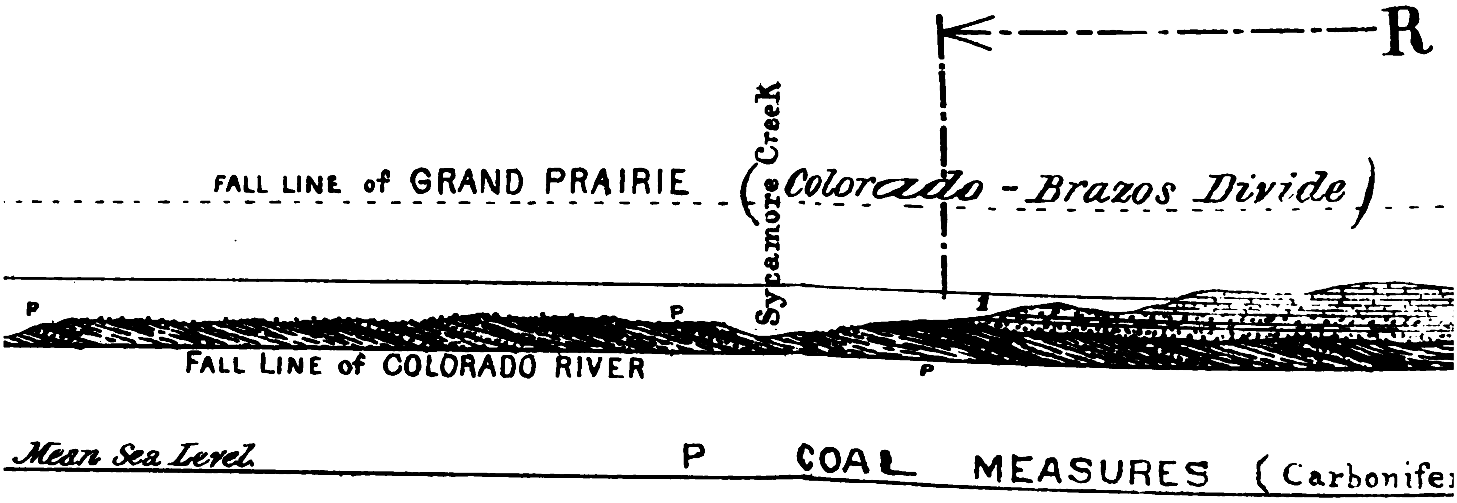
The present topographic forms of the Grand Prairie can be rea
understood. The firm, persistent limestone and harder chalks prod
escarpments of stratifiation. Thus the outcrop of the Goodland li
stone in Indian Territory forms an escarpment some 200 miles lo
overlooking the valley of the Trinity and Paluxy sands. The D
Creek, Denison, Fort Worth, and Caprina limestones produce sim
landmarks. The softer disintegrated chalks nearly always occur
these places on the slopes or faces of the escarpments, while the cl
and sandy terranes, as the Walnut clays and Trinity and Palu
sands, weather into extensive plains or semivalleys extending inter
ward from the escarpments. Where the head-water erosion of t
newer drainage above mentioned encroaches upon the shorter and mo
precipitous drainage slopes of the older and deeper incised drainag
buttes and mesas are evolved. Where the Comanche Peak bed su
mounted by the Caprina limestone constitutes the divides it is usele
to expect flowing wells. These buttes are invariably of the followi
types: (1) Flat-topped mesas, surrounded by precipitous escarpment
(2) basal plains or pediments composed of Exogyra texana clays a
the Gryphdea beds; (3) slopes of 45° composed of the Comanc
Peak chalk. If the divide is composed of the Glen Rose beds the r
sulting buttes are usually conical, encircled by benches resulting fro
the alternating soft and hard layers. The great difference of hardne
in the respective terranes is also productive. This is especially tr
of the eastern half of the Grand Plains area of plains that, coincide
with the prevailing dip, and terminating eastward against an escar
ment of the overlying beds, invariably deflect the drainage parallel
their strike. On the west it is shown by a descending escarpme
These dip plains are beautifully shown in northern Texas and southe
Indian Territory, where they constitute the prevalent topography a
extend over vast areas. The prairie between Fort Worth and Weathe
ford is a fine example of dip plain, as well as are all the prairies
north Texas.

WATER CONDITIONS OF THE GRAND AND BLACK PRAIRIES.

These regions, especially the Grand Prairie, possess peculiar wat
conditions, which are the product of the structural and topograph
conditions we have described.

The water features are of three distinct classes, to wit: (1) The Gra
Prairie Drainage, or river system; (2) the Mammoth Springs of S
Antonjo, San Marcos system; (3) the Waco-Fort Worth and the D
las-Pottsboro artesian systems.

The Rivers of the Grand Prairie.—Two of the great river systems
Texas are found in the Grand and Black prairies, the Red, Colora
Brazos, and Pecos, or rivers of the plains and mountains, cut throu
them far below the present surface and drain little or none of the s
face, as will be seen by examining a map. The second system is
peculiar to the region, consisting of streams which originated upon
surface when the coast line of the Gulf of Mexico almost coincid

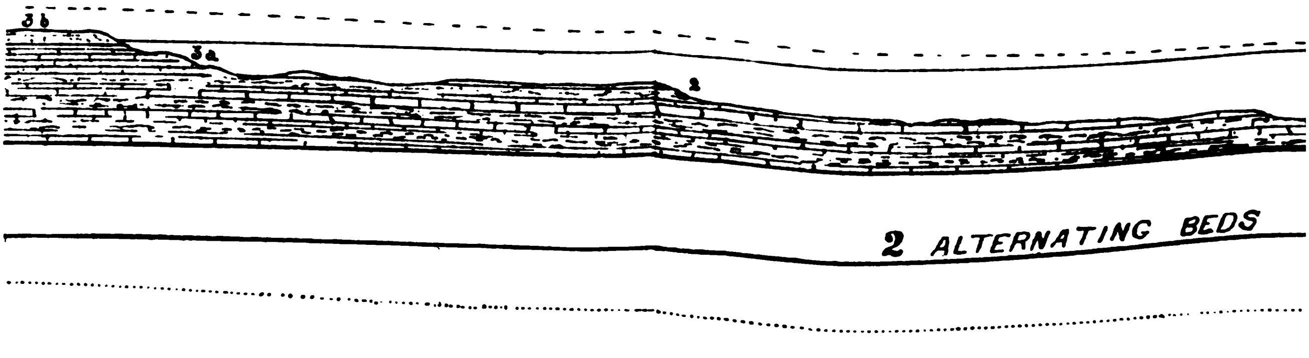

R
FALL LINE of GRAND PRAIRIE
Sycamore Creek
(Colorado - Brazos Divide)
P
P
1
FALL LINE of COLORADO RIVER
P
Mean Sea Level.
P COAL MEASURES (Carbonifer

Geologic Section and Profile

along the COLORADO RIVER through AUSTIN
from SMITHWICK MILLS, Burnett County
to LITTIG, Bastrop County, TEXAS.

By

ROBERT T. HILL & J. A. TAFF



ie present eastern border of the Grand Prairie south of the Colo-
nd the east line of the Black Prairie north of that river. Since
iergence of the plain they have been deflected mostly into the
s of the older system.

Grand Prairie streams are analogous in origin to the small
s that now fringe the coastal plain near the Gulf, and a slight
on of the coast would leave the latter in the same position as the
. They drained the Grand Prairie when it was a coastal plain,
ce its elevation have been cutting deeper and deeper into its sur-
erosion and extending their sources westward by head-water
. This system of streams is inconspicuous in Indian Territory,
reases in size and importance southward. The central or Fort
Waco division of the Grand Prairie is represented north of the
by the Paluxy and Trinity group; between the Brazos and the
do by the Bosques and the Leon; south of the Colorado by the
sas and the San Gabriel. The Conchos, the San Saba, and Llano
long to this group in origin but have cut through the Grand
floor.

streams of this class having their origin in the eastern edge of
wards plateau are the Pedernalis, San Marcos, Guadalupe, Cibilo,
, San Antonio, Frio, Hondo, Sabinal, Nueces, Elm, Las Moras,
River, and Howards Creek. An interesting fact concerning all
e streams (except the main Trinity, the Concho, San Saba, and
which have completed their head-water journey across the plateau)
their fall or gradient is much greater than that of the coastward
f the Grand Prairie. From this feature their valleys become
and wider to the eastward, making flowing wells a possibility
aving large areas of flat-topped divides between them. This
topographic fact has an important influence in the artesian con-
as will be shown later.

ther interesting feature of many of these streams is that their
course is composed of arroyos, dry and waterless except in time
m water. Their medial portions where the stream has cut below
manche Peak group are usually fed by springs from the sands
ternating beds; towards their lower portion they often disappear
h the surface of the limestone débris, pools of water remaining
the ground at short intervals, from which a stream may flow a
t and then disappear in the rocky débris.

h of the Colorado these streams are of secondary value for irri-
, but south of that river they increase in importance and in the
ds Plateau are quite extensively used and can be made of great
In this region the streams cease running (except when aug-
d by the great springs to be described later), when they reach the
f the great Rio Grande embayment or the Black Prairie plain,
imbibed by the pervious strata.

Rio Frio is a good example of these rivers. From the point where
ream crosses the Southern Pacific to its mouth it flows in the al-
flat, gravel-covered region of the Rio Grande embayment. In
rtion of its course, although nearer its mouth, it has little water,
none. Ascending the stream northward it appears to flow from
ntain gorge, but upon closer study these mountains (which are
to the northward from the Southern Pacific road as far west as
rd) are seen to be escarpments of the Great Edwards Plateau.
the river flows through a valley often several miles wide, sur-
d by high hills on each side, filled with ancient gravel deposited
stream when the gulf waters reached into this embayment. The

stream is clear and swift, flowing 1,000 gallons per minute. In a few miles the walls close in and the valley averages 2 miles in width for 15 miles or more, with good agricultural lands in its bottoms.

About 25 miles north of the railroad the precipitous yellow bluffs of the cañon begin to assume higher proportions, and numerous springs begin breaking out of the oölitic marls and sandy clays of the alternating beds. The dip of the strata here is 74 feet per mile. From Van Pelts to Leaky, the county seat of Edwards County, and thence to Frio water hole this great cañon continues, the water generally increasing upstream from the many springs. These springs are very frequent and in the aggregate flow enough water to irrigate thousands of acres. At Frio post-office there are over a thousand acres irrigated from this stream.

From Frio water hole on to the head of the river the water ceases, but the great cañons continue until the rocky summit is reached. Crossing this plateau for a few miles, the head of the south fork of the Guadalupe, descending to the Black Prairie, is reached and the same phenomena are seen, to wit: (1) A long stretch of head-stream arroyos; (2) a medial portion consisting of deep cañons, with widening valleys, where the water becomes abundant and sufficient for magnificent irrigation enterprises, the source of supply being numerous constant springs from the alternating beds which form the walls of the cañon; (3) a lower portion in which the volume decreases through imbibition of the stream débris.

The supply of water for these streams can be clearly seen in the springs in the lower beds of the Edwards Plateau, which flow out at water level and could no doubt be greatly increased in volume by artificial means and preserved for irrigation by suitably lined reservoirs and ditches, which could be constructed with cheapness, because the entire mass of the plateau is composed of rock suitable for making hydraulic cement.

The valleys of the streams of the Edwards Plateau, as the Pedernalis, the Guadalupe, the Comal, Medina, etc., are among the most beautiful, picturesque features of our country, and proper usage of their waters would increase the productivity of the region a thousandfold.

The source of the spring waters which supply these streams is the same as that which supplies the wonderful artesian wells and the mammoth springs of the San Marcos-San Antonio system. Although its surface is an arid country, the Edwards Plateau is a great water reservoir of priceless value to the State of Texas, and the time will soon come when it will be considered criminal to permit one drop of its valuable flow to reach the sea unused.

The streams of the system north of the Colorado are not relatively so important for irrigation, owing to their slighter volume and fall, but by a little care and mechanical aid the capacity of thousands of acres which are now idle or unprofitable could be made more profitable. This is especially true of the Lampasas and Leon, Bosque, and Paluxy.

The mammoth springs of the San Antonio system.—Following the boundary of the Grand and Black Prairie regions of Texas from Dallas to Del Rio, a distance of 400 miles and increasing in volume southward there is a series of most remarkable springs, which rise out of the ground and flow off as veritable rivers. These springs are often of such magnitude and beauty that it is impossible to convey a proper conception of them. They do not break out from bluffs or fall in cascades, but appear as pools often in the level prairie, filled with water of a beautiful blue color which flows swiftly silently away by the outlet which drains them.

he pools are carpeted with exquisite water plants, forming a waving ss in which may be seen many fishes. So transparent and crystal- are these waters, that objects 15 to 20 feet below the surface appear y a foot away. No tint of surface débris or of storm sediment mars crystal clearness, for they are purified by rising through nature's er a thousand feet of the earth's strata.

t is an interesting fact to note that the trend or line of these great ings coincide almost exactly with the west edge of the Black Prairie d with the line of the great Austin Del Rio strike fault, which fol- vs its parting with the Grand Prairie. A study of rocks in the inity of the springs will always show that there is a system of joints fractures coinciding with this great fault line and it is up in these sures that the waters force their way. In other words, these springs ve their origin in a deep-seated rock and are forced to the surface by drostatic pressure from the basal Comanche series. They are natural tesian wells.

The most conspicuous of these springs are at San Antonio, Del Rio, n Marcos, New Braunfels, and at Austin. In addition to these there e magnificent springs at Round Rock, Georgetown, Salado, Belton, valde, Las Moras, Clark, and other places. The Cedar Springs south- st of Dallas are probably the most northern of the line. There are so numerous small springs of the system which need not be mentioned.

In order to convey an idea of the magnitude of these springs, I shall escribe one or two of the most important. Perhaps the largest of the roup are the springs at the head of the San Antonio River, a few iles out of the city of San Antonio. They flow out of the ground in reat volume, 23,000 gallons per minute, nearly 50,000,000 gallons per ay, forming an exquisite lake from which flows through the heart of he city the magnificent river of San Antonio.

Around this marvelous group of springs and upon the banks of its utflow were located the most ancient Indian settlements, or Pueblos, f Texas. The early Spanish missionaries, seeing the beauties of the place and its natural advantages, located six magnificent missions here, within a short distance of one another, with surrounding plantations. The Spanish thus conducted the instruction of the natives, whom they employed in the cultivation of farms and gardens irrigated by the spring waters. The ancient acequas or ditches, followed by the older streets, shape the present outline of the city.

At present the large springs at the head of the river furnish water for the city of 48,000 inhabitants without producing any very appreciable decrease in the outflow in the river, the waters of which are still used to irrigate thousands of acres of gardens and farms, and is sufficient to irrigate many thousands more, although unfortunately most of the water flows to the sea unused.

The springs at Del Rio are, perhaps, the next largest in size. They break out upon the edge of the Edwards plateau, or southern continuation of the Llano Estacado, 2 miles east of Del Rio, and about 5 miles from the Rio Grande. The pool is almost as extensive and beautiful as that at the head of the San Antonio River. From the deep-seated rock at its bottom the water can be seen welling up in a great column, and it has the same peculiar greenish blue of the other streams of this class. No live oaks or other trees surround it, and it stands alone, a great fountain in the desert. From examination of the rocks from which this spring bursts, the Fort Worth limestone, it is seen that they have the same perpendicular joints and faults found at San Antonio and Austin.

The outflow from the pool, a bold rushing stream, runs off some 5 miles distant to the Rio Grande, which it excels in volume. This spring stream, in addition to running a mill and supplying the village with water, is partially utilized to supply 15 miles of irrigation ditch and irrigate 5,000 acres. The water taken out for the ditches makes no perceptible diminution in the volume of the creek.

The springs of the Comal at New Braunfels are also of this gigantic character and flow off an immense volume of water, which could be utilized for irrigation.

At the village of San Marcos, however, is a large, beautiful, and well-situated spring. It breaks out at the foot of the bluffs of the great fault line and is the source of a beautiful river flowing at least 20,000 gallons per minute. This has long been a famous resort in Texas on account of its beautiful scenery and water. The springs form a lake nearly half a mile long, which overflows into a beautiful stream known as the San Marcos River. At the lower end of the lake a mill and ice factory are run from the water power of this spring, and while no irrigation is conducted there is no reason why this volume of water should not be utilized to irrigate the fertile Black Prairie plain, through which it flows.

In the vicinity of Austin are other groups of artesian springs of remarkable beauty and scientific interest, breaking, along the line of the great fault in which the Colorado flows, from the foot of Mount Bonnel in the western suburbs of the city, to where it emerges from its cañon of the Grand Prairie region into the broad bottoms of the Black Prairie.

Along this line from the foot of Mount Bonnel to near the mouth of Barton Creek there is a series of springs* pouring up through the great rock joints. Beginning at the north, the chief of these springs is 6 miles north of Austin; Mount Bonnel and Taylor springs are east of the foot of Mount Bonnel; Bee Springs east of the river; Barton Springs and six unnamed springs west of the river. Of these Taylor and Barton springs are the best known. The latter group occur in each side of Barton Creek, near its junction with the river and flow superb volumes of water. A mill is run by the water power from Barton Springs, but it would be impossible to conduct irrigation with the waters owing to their low position relative to the Colorado. The water power which is now mostly wasted should be utilized. These springs are beautifully situated and are the favorite resort of the people of Austin; they are surrounded by pleasing groves of pecan timber and picturesque rocks. Their aggregate volume must reach many thousands of gallons per minute.

Almost due north of Barton Springs, along the same great fissure, and at the low-water level of the Colorado there is another outburst of artesian springs, but owing to the fact that they are at the base of a great bluff and accessible only by boat few people have seen them. This group of springs flows a great volume, but, inasmuch as they break out in the river's edge, it is impossible to gauge them. The aggregate volume of these springs near Austin is so great that the volume of the the river is materially increased by their accession. Equally valuable but of less volume are the springs around Georgetown, Salado,

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* These springs unfortunately are all near water level of the river, but they are of great value.

Belton and they are all of similar origin and nature. The Colorado
er and Barton Creek cross this fault line near Austin; hence the
irrence of the springs on both sides of the river.

rom the similarity of color, temperature, and occurrence of this
at chain of springs, extending half way across the State, there can
io doubt that they are all of similar nature and origin, and that they
underground waters forced up by great hydrostatic pressure through
fissures of the Balcones fault system along the parting of the Black
l Grand prairies.

A comparison of their waters and temperature with those of the arte-
n wells, together with the similarity of the geological structure,
ves no doubt that they have the same origin, the great pervious beds
the Trinity division of the Comanche series which are the foundation
the Grand Prairie, and imbibe the waters at an outcrop at a higher
itude along its western edge.

The volume of water flowing from these springs aggregates many
llions of gallons per minute, and since they have never shown any
ninution or increase of quantity in seasons of drought or rainfall,
ese facts are valuable evidence of the vast extent and inexhaustibility
the source of underground water which supplies them and the deeper
ells of the Fort Worth-Waco system.

The artesian waters of the Black and Grand prairies.—We have now
rived at the discussion of the greatest artesian belt of Texas, the sys-
m of wells found beneath the Grand and Black prairies.

In no portion of the country has there been a grander development
f artesian wells than in the past five years in the Grand and Black
rairie regions of Texas. At numerous places throughout its extent
iagnificent flows of water have been secured and what ten years ago
as in many places a poorly watered district now abounds in magnifi-
ent artesian wells, which supply water to cities and farms in quantity
arge enough to make many new industries possible, besides furnishing
vater to irrigate many thousands of acres.

It has been the writer's fortune to observe and encourage this artesian movement from its conception, and in the following pages he proposes to present the underlying principles of the artesian supply, and to point out, as a result of years of study, the areas of possibility and failure and the probable flow obtained, so clearly that wells may be located with certainty.

The artesian waters of this system are so voluminous, and the area over which they can be produced is so extensive that it justly deserves the distinction of being called one of the greatest artesian areas in America—if not in the world—extending as it does, from near Red River, Denton County, to the Rio Grande at Del Rio, a distance of 448 miles in length, and averaging 40 miles in width.

This area over most of which flowing wells can be obtained, is about the size of Minnesota, Nebraska, or North or South Dakota, and equal to the combined area of many of the smaller States, and 22,000 square miles larger than the average State or Territory of the Union, omitting Texas. The area in Texas in which the wells of the Fort Worth system are obtainable, is also greater than the area of any State in the Union, except Arizona, Montana, Nevada, New Mexico, Wyoming, and Kansas.

To deal with such a vast area would be difficult were it not for the great uniformity and similarity of the structure of its geologic features. The wells vary in depth from 50 to nearly 2,000 feet with every intervening depth. They also vary in volume or flow from less than a gallon a minute to a thousand, and in pressure from nothing to maximum. Although distributed over a wide country, there are many places where these wells can not be obtained, which it is necessary to point out, and many where it can be obtained which are now not known.

The history of this wonderful artesian development is almost too recent to be written, and its development is solely due to the spontaneous enterprise of the citizens who have in every instance except one made the experiment at their own expense. This exceptional instance of State experimentation at Austin on the capitol grounds was not conducted to the fullest extent. Ten years ago a citizen of Fort Worth sunk a shallow artesian well for the purpose of obtaining water for stock. This was secured at a depth of 300 feet. Almost immediately nearly a hundred wells were sunk to the same-water level. As is inevitably the rule, the wells stopped at the first water struck, and not until the past year has Fort Worth discovered that her drills had not yet penetrated the lowest and greatest water-bearing strata.

The purity of this artesian supply for domestic purposes and its healthfulness gave Fort Worth an enviable superiority which her rival cities were not slow to imitate, and as a result of her success nearly every city and village in the Grand and Black prairie region and in fact throughout the State, made artesian experiments. A few of these were put down in unfavorable locations and were failures, but hundreds more were successful and to-day most of the cities of the State which before this artesian epoch were without good water are supplied with an abundance.

Wells have been successfully obtained at Fort Worth, Waco, Dallas, Denton, Taylor, Austin, San Antonio, McGregor, Gatesville, Belton, Morgan, Glen Rose, Paluxy, Whitney, and other places which will be enumerated later. Their number and the wide area over which they are found is indicative of a general source and occurrence by which their distribution, value, and possibility can be predicated with considerable certainty. To point out these is the chief object of this paper.

While this development of artesian water in cities was progressing, independent discoveries were being made by the farmers and stock raisers along the western margin of the area, where in certain valleys, like those of the Bosque and Paluxy, shallow wells were struck, and now there are hundreds of these, many of which are used for irrigation and for watering stock.

Counting the aggregate water of the great artesian wells and artesian spring rivers, there is flowing from the underlying rock sheets of this region at least 300,000 gallons of purest water per minute, 1,800,000 per hour, or 41,200,000 gallons per day, a volume as large as many notable rivers.

When it is considered that the first water was experimentally reached only twelve years ago, and the greater underlying sheets only four years ago, the future possibilities are beyond estimate.

Availability of the water sheets of the Black and Grand prairies.—In order to fully understand the laws of these wells it is necessary first to thoroughly study the simple stratigraphic arrangement of the rock sheets of the region, which can be best understood by reference to the cross-section profiles and maps accompanying this paper. Typical cross sections and profiles of the Black and Grand prairie regions are given extending from the interior coastward. From an examination of these it will be seen that the general structure consists of the sheets described revious pages, inclining coastward at a small angle only slightly ter than the topographic slope, which, as asserted in the introduc- chapters of this paper, constitute the ideal conditions for transmis- of artesian water. These rock sheets have different capacity for bition and transmission of water. The more porous ones are water ring; their capacity is not only proportionate to its facilities for im- tion and transmission, but its area of outcrop.

Water-bearing strata.	Thickness.	Retaining or nonwater-bearing strata.
	Feet.	
he Navarro or Glauconitic sands..	300	7. The Taylor marls. The Austin chalk. The Eagle Ford clays.
he Lower Cross Timber or Denison sands.	100	8. The Washita division, Fort Worth limestone, Duck Creek chalk, Kiamitia clays. 4. The Comanche Peak division, the Caprina limestone, the Comanche Peak chalk, the Walnut clays.
he Paluxy sands....................	100	
ortions of the Glen Rose beds.....	700	Portions of the Glen Rose beds.
he Trinity sands.		

The water-bearing strata.—Of the water-bearing strata above men- ned the Glauconitic sands, which occur along the eastern border of e Black Prairie, can not be considered in the discussion of the prairie gion, for any wells penetrating to them would be in the regions to the stward. Omitting these (the Glauconitic or Navarro sands) from con- deration, there are five great water-bearing sheets of the section, sep- rated by impervious layers, as follows:

4. The Lower Cross Timbers, or Denison (in part) and Dakota sands.
3. The Paluxy sands.
2. Portions of the Glen Rose beds.
1. The Trinity sands or Upper Cross Timber sands.

Each of these sheets outcrop in characteristic area, and incline to he eastward at a slightly greater angle than the average of the topo- raphic slope beneath the overlying beds, transmitting the water under ydrostatic pressure to lower depths. Each sheet has great differences n thickness, extent, capacity for imbibing waters and for transmission; also in chemical composition which affects the quality of the water. The exposed area or outcrop of the water-bearing sheet constitutes the receiving area for the stratum which receives the rainfall. The continuation of the receiving rock sheet beneath the overlying beds constitutes the water-bearing sheet.

Now it is evident, since they incline eastward beneath the overlying sheets, that these strata get deeper and deeper into the earth to the eastward and are overlaid by more rock sheets; so that the Trinity sands which constitute the surface of the Upper Cross Timber Valley in part, between Millsap (altitude 822) and Weatherford (altitude 1,000), average 1,000 feet above sea level. At Fort Worth, 28 miles east of Weatherford, they are only 280 feet above sea level; at Dallas, 58 miles east, they are 960 feet below sea level, or 1,566 feet from the surface, and so on as we go eastward, estimating that these strata incline at the rate of 28 feet per mile.

The Paluxy sands which outcrop just west of Weatherford and around the base of Comanche Peak are 1,400 feet above the sea; at Fort Worth

200 feet above the sea (or 300 feet below the Trinity River level, and 590 below Tuckers Hill), at Dallas they are 800 feet below the sea, and at Terrell 2,300 feet below sea level, or 3,100 feet below the surface.

The Lower Cross Timber sands (which do not outcrop west of Fort Worth) are the surface formations between Arlington and Handy. They are from 731 to 800 feet below Dallas, and at Terrell 2,475 feet, the dip, about 45 feet per mile, being slightly greater than that of the Trinity sands.

Not only do these rock sheets become deeper and deeper to the eastward, but they are successively covered by other rock sheets which must be drilled through. While a drill upon the western edge would begin in these Terrell sands, which are there the surface formations, on the eastern margin of the Black Prairie the drill must penetrate the entire thickness of the two Cretaceous formations to reach the lowest water beds of the Trinity, or between 3,500 and 4,000 feet, as at Terrell, Greenville, Corsicana, Marlin, and Thorndale.

A drill at Greenville, Terrel, Kaufman, Corsicana, Thorndale, Marlin, or any other point along the eastern margin, would be obliged to penetrate all the formations, including the five water beds, to reach the Trinity sands. A similar drill-hole well in the main Black Prairie, as at Mesquite, Waxahachie, Hubbard, Temple, Taylor, or Manor, would not penetrate as many rock sheets by the thickness of the Ponderosa marls and Glauconitic beds to the east. A drill in the Austin-Dallas chalk would penetrate fewer strata by the thickness of the Ponderosa marls, and one in the Eagle Ford shales still less. Drill holes sunk in the Black Prairie, Lower Cross Timber sands, or the Grand Prairie, go through respectively less thicknesses to the westward until finally a well in the western margin of the Upper Cross Timbers gets the same water at the surface in ordinary surface wells without artesian flow. A well drilled west of the Trinity sands can not possibly obtain water from any of the sheets of the coastward incline, for they do not occur west of that line.

By a study of the maps and profiles it will also be evident that the entire set of water-bearing sheets underlie all of the country east of the Lower Cross Timbers north of the Brazos, although some of them may be practically unavailable through great depth or high altitude of the drilling station. Between the Lower Cross Timbers, and the Paluxy sands, *i. e.*, the eastern margin of the Upper Cross Timbers, all the water-bearing sheets will be available; except that of the Dakota or Lower Cross Timber sands, for the latter does not extend over the region west of the Missouri, Kansas and Texas Railway, except in northern Johnson County, but has been worn away by erosion.

In the portion of the Grand Prairie west of the Paluxy sands south of where they disappear by thinning out, a drill will start geologically below the three upper water beds and penetrate only two sets of water strata—the Trinity and alternating beds, as in the wells at Glen Rose, Iredell, and Pidcocks Ranche. Finally, in the eastern margin of the Trinity sands the well will only penetrate the Trinity sands as at Bluff Dale and Paluxy. In all of these cases the general rule is maintained, that the depth of any rock sheet in the series decreases to the westward until it ceases by outcrop.

Geologically speaking, it might be said that nature has done much to help the driller, for wherever a rock sheet is cut through by a stream or entirely removed by erosion the artesian engineer has that much less to drill through.

By this process of erosion it will be seen that the well at Terrell, al-

gh 2,200* feet deep, has not yet penetrated to the rock at Dallas,
ch occurs at the surface, owing to the removal by erosion at Dallas
he strata through which the well at Terrell has been drilled.

he citizens of Dallas are 2,200 feet nearer the Trinity water sheet,
their wells, averaging 800 feet deep, do not reach the Fort Worth
estone, upon which the latter city has erected its drill derricks, and
still 1,500 to 2,000 feet above the great Waco supply. Nature has
noved for Fort Worth not only the total thickness penetrated by the
rrell well (2,200 feet) plus that of the Dallas well (750 feet), but also
Lower Cross Timber sands (plus 200 feet) from which Dallas re-
ves her water supply, and brought Fort Worth 3,000 feet deeper or
arer than Terrell to the main Trinity supply.

Finally the Fort Worth drills until the past year have not penetrated
low the Paluxy sands, and hence not to the strata upon which Glen
ose is situated, so that nature has removed by erosion for the people
the latter place the whole thickness of rocks represented by the
ort Worth well placed on top the Glen Rose, plus that of the Dallas
ells on the Fort Worth, plus the Terrell wells on top the Dallas, or
early 3,500 feet of strata.

It is evident to those who have followed the statement of the strati-
raphic and topographic conditions of the regions that the numerous
rtesian wells flow from the four great rock sheets, those of the Lower
ross Timber sands, the Paluxy sands, the various sandy and öolitic beds
f Glen Rose, and the Trinity of Upper Cross Timber sands. The Glen
ose and Trinity beds occur in such close proximity and merge into each
ther so closely, that they will be discussed as one water-bearing group
veraging 700 feet in thickness, from which Waco secures her "Jumbo"
low.

Each of these water-bearing beds has been penetrated by well borings.
shall discuss the receiving and available areas of each sheet.

The Dallas-Pottsboro Group of the Black Prairie region, or the artesian
wells of the Lower Cross Timber (Dakota) flow.—The flowing artesian
wells of Pottsboro, Denison, and Dallas, and the nonflowing artesian
wells of Sherman, Paris, and Midlothian, a north and south belt of
country extending from Denison, near the Red River, to near the Brazos, all have their origin in the sandy strata of the Lower Cross Tim-

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* Section of drill hole at Terrell, Tex., with continuation of rock sheet to be penetrated:

Glauconite beds	Soil	15	
	Joint clay	31	
	Rock	10	
	Sand	20	
			76
Ponderosa marls	Shales and clay	185	
	Soft rock	10	
	Blue shale	340	
	Rock	8	
	Blue shale	484	
	Rock	8	
	Blue shale	600	
			1,607
Austin chalk	Solid rock		195
	Lignite		12
	Lime rock		195
End of drill hole			2,200
Eagle Ford shale			525
Lower Cross Timber sand or first water at about			100
			2,800

bers, which constitute the receiving area of the Dallas-Pottsboro flowing wells, as will be shown by the following evidence:

Within a circumference of 2 miles of Pottsboro (alt. 769), in Grayson County, situated in the medial beds of the Eagle Ford clays, four wells were bored which struck a flow 250 feet from the surface in the Lower Cross Timber sands, which outcrop a few miles west and northwest at a higher altitude. These wells are estimated to flow 25,600 gallons per day and are of magnificent volume and pressure.

In drilling them no chalky strata were struck, inasmuch as they commenced geologically below the Dallas chalk, the lowest limestone of the Black Prairie region, and did not reach to the highest limestones of the Comanche series, but found water in the Lower Cross Timber sands. At Sherman (alt. 747), some 20 miles southeast, situated geologically on rock sheets higher (on the base of the Austin-Dallas chalk), a well was drilled 632 feet through the Eagle Ford clays and into the Lower Cross Timber sands, from which the water rose to within 100 feet of the surface, but did not flow, probably on account of the slight pressure and leakage of water from the sheet at its outcrop near Cook's Springs and other points north of the city, and possibly because the sands were not penetrated deep enough.

At Dallas (alt. 436 to 500 feet), some 70 miles south of Sherman, and on the same rock sheet (the Austin-Dallas chalk), but some 300 feet lower in altitude, numerous wells have been struck in the top of the Lower Cross Timber sands, at depths (varying with the altitude of the surface and penetration of the sands) from 672 to 800 feet. All of these struck water in the Lower Cross Timber sand beds which outcrop from 15 to 25 miles west of the city, furnishing in most instances an abundant supply. There are apparently several veins of water, owing to the fact that the Lower Cross Timber sands have many clay beds alternating with them, the first being at 632 feet and another at 734 feet. Until about one year ago only the upper waters, with a very weak flow, had been struck, but the county and city authorities combined sunk a deeper well on the public square, which produced about 200,000 gallons daily. Since that time others have been struck, notably at the Exall building, the McLeod hotel, the Cockrell building, and at the office of the Dallas News. The last was a most characteristic enterprise of that paper, and through the courtesy of Mr. Doremus, its editor, I am enabled to present an illustration, which will convey an idea of the appearance of the Dallas well.

A section of the newspaper well illustrates the character of the strata passed through at Dallas, and by comparison with those at Waco and Fort Worth and Austin, it will be seen that the latter go into strata entirely different and below those penetrated at Dallas. A similar comparison with the Terrell drill record, 30 miles east, will show that the latter has not yet reached the water sands, although 2,200 feet have been passed.

Every foot of the stratification penetrated by the drill can be plainly seen outcropping on the surface between Dallas and Handy stations, 23 miles west, on the Texas Pacific road. (See profile 1.) The sand and gravel first penetrated is the old terrace deposit of the Trinity Valley, on which Dallas is built. This can be seen resting on the white limestone (No. 3) or Austin-Dallas chalk in various parts of the city. This chalk is exposed in the bluffs of the river at the Texas Pacific bridge, and is the cliff formation of the suburb of Oak Cliffs. In the bluffs of Mountain Creek, which follows the escarpment valley of the Austin chalk from Oak Cliffs to its head, can be seen the clays (No. 2) as well as on the surface of the Black Hog-wallow Prairie, extending westward to the Lower Cross Timbers; the latter begin about 18 miles west of Dallas, where the upper layers, from which Dallas secures her water, are exposed, thus giving the strata an inclination of about 45 feet to the mile towards Dallas, as can be measured in the bluffs of chalk south of Eagle Ford. Notwithstanding the wonderful simplicity of the stratification there are many people in Dallas who attribute all kinds of remote origins to these waters, as the Rocky Mountains, 1,000 miles west; while one leading citizen has traced them across the great Ouachita Mountains, in Arkansas, to the Ozark Mountains, in Missouri. He says: "My idea is that the source of the artesian supply here is in the Ozark Mountains, in southern Missouri and northern Arkansas. It is not in the northwest, for if it were Fort Worth would have an immense supply of artesian water, whereas it is limited to the first light flow that we have struck," etc. This opinion had hardly been delivered when Fort Worth exploded his Ozark hypothesis by penetrating the basal Trinity flow and obtaining unlimited water.

The fact that flowing wells are obtained at Arlington (altitude 613), in the eastern edge of the Cross Timbers, from these sands at depths from 30 to 150 feet is corroborative proof of the fact that they supply Dallas, and from the fact that they have sufficient pressure to flow at this altitude of 613 feet it may safely be assumed that artesian water from the same Lower Cross Timber sands can be struck (unless there is some unknown disturbance in the strata east of Dallas) at all points in Dallas County, whose altitudes are less than 613 feet and at a depth to be estimated by multiplying the distance in miles to the east margin of the Upper Cross Timbers by 50, the approximate inclination in feet of the strata per mile,* and subtracting from the total the difference in altitude. Thus at Mesquite (altitude 509), 30 miles east of Arlington, the eastern margin of the Cross Timbers or receiving area, the depth of the water may be approximately estimated as follows: $(30 \times 50)-(618-509)=1{,}500-109=1{,}491$; and at Terrel (altitude 514), 50 miles east of the Lower Cross Timbers, the Lower Cross Timber sands would be approximately: $(50 \times 50)-(618-514)=2{,}500-104=2{,}396$; at Grand Prairie (altitude 500 feet), 7 miles east of Arlington, the water would be: $(7 \times 50)-(618-500)=350-118=232$ feet.

At Midlothian, southwest of Dallas, 25 miles in Ellis County, is another experiment in the Lower Cross Timber sands, but the well was not bored deep enough into them, and the water is of poor quality. It rises to within 30 feet of the surface.

Section of well at Midlothian:

	Feet.
Austin chalk and soil	24
Eagle Ford calcareous clay shales	234
Light yellow sandstone	20
Total	278

It is evident by comparing the Dallas section that this Midlothian well has not yet reached the main stratum of sands, but should penetrate at least 250 feet more of clays. The wells at Sherman, Dallas, and Midlothian are about the same distance from the outcrop of the Cross Timbers, and all begin in the same stratum, the Austin-Dallas chalk.

Near the eastern margin of the Lower Cross Timbers is another line of experiments from which we can learn much, to wit, at West Denison and Pottsboro, near the northern margin, at Arlington, west of Dallas, and at Files Valley, in Hill County, west of Midlothian. The magnificent flow of the Pottsboro wells has already been described. At Arlington there are many wells which overflow. They vary in depth from 15 to 120 feet, and begin and continue in the sands. At Files Valley (altitude 460 feet), in Hill County, just east of the Cross Timbers, J. R. Lane has bored 123 feet through the basal Eagle Ford shales and Upper Cross Timber sands, striking a small flow of 3 gallons per minute.

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* This inclination may be more or less by a few feet, as it is impossible to determine it more accurately in the clay.

This line of wells at Denison, Pottsboro, Arlington, and Files Valley, although I should like more evidence, indicates by the outcrop that the Lower Cross Timber water supply decreases southward because the receiving beds thin out in that direction.

In the region between the Brazos and Pottsboro, the capacity of the Lower Cross Timber sands for water is shown by the fact that wherever dug into they yield water. Numerous surface wells occur throughout their extent, as well as springs, as Cooks Springs, near Denison, which flow from them. At Denison these sands have been literally mined for their water of saturation by the water company which supplies the city, an interesting method of procuring underground water from the rock structure. A large area southwest of the city is underlaid by an extensive sheet of the porous ferruginous Lower Cross Timber sandstone of great imbibing and transmitting capacity. A vertical well 25 feet in diameter was sunk from which a lateral tunnel was run into the sandstone, parallel to its bedding. The percolation soon filled this tunnel and well, constituting a complete reservoir, from which the water is pumped through the city.

This is an ideal method of utilizing the water of saturation, inasmuch as it exposes to free percolation by the walls of the tunnel a vastly larger surface of saturated strata than could be secured by a vertical shaft or well. This method of obtaining water is worthy of consideration elsewhere.

These tunnels at Denison show that the Lower Cross timber sands are completely saturated with water below the line of evaporation, which is about 25 feet in this region, judging from the average depth of surface wells.

The waterworks company at Denison has also recently drilled three wells into these sands and secured a fine flow of 20,000 gallons per day, each at a depth of 200 feet. The area of Grayson County in which these wells can be obtained, however, does not extend north of Main street in Denison, nor into the eastern part of the city, as has been proven by experiment.

The total area of the Lower Cross Timber sands in Texas, from Red River to Waco, as carefully mapped out by my directions, is 794 square miles. The average rainfall is 36 inches per annum over this area. Of this amount at least 50 per cent is imbibed and becomes the source of artesian water.

Extent of the Dallas, or Lower Cross Timber artesian area.—According to the well known hydrostatic law that water will not rise above its level, it is evident that artesian wells can not be expected from the Lower Cross Timber sands except at points to the eastward of their western margin and at a lower altitude.

The altitudes of the Lower Cross Timber sands, between the northwest corner of Grayson County and the Brazos River, are as follows:

East edge.	Feet.	West edge.	Feet.
South Denison	712	Dexter	850
Lewisville	485	Denton	711
Arlington	616	Roanoke	656
Alvarado	700	Handy	750
Vaughin	550	Cleburne	800
		Whitney	650

Comparison of these altitudes, shows the average of the eastern edge to be 600 feet and of the western edge 736 feet. Since the white rock cliffs, of the Austin-Dallas chalk to the east average 750 feet, except where cut into by drainage as at Dallas, it is evident that the area where a flow well is possible will be (1) the country of the Eagle Ford clay prairies in Grayson, Collin, Denton, Dallas, Tarrant, Hill, and Johnson counties, which lie between the escarpment of the White Rock and the Cross Timbers. (2) The eastern edge of the Cross Timbers themselves. (3) The valley of the Trinity River, an area of at least 1,000 square miles. From the geographic distribution of the formations the depth of the wells in these areas can not exceed 900 feet on the east and 35 feet in the west. A fourth possible area is the eastern belt of the Black Prairie as at Greenville, Terrel, Kaufman, and Corsicana, where these sands may be struck at a depth greater than 2,200 feet, and good negative or nonflowing wells obtained.

Owing to the absence of the sands south of the Brazos division, they furnish no water in that region, and hence the wells at Waco and Austin although beginning in the Austin-Dallas chalk, as at Dallas and Sherman, do not get any water until the Paluxy and Trinity sands are reached.

In the Dallas chalk or White Rock region it is highly improbable that flowing wells from the Lower Cross Timber source can be struck except in the drainage valleys, like that of the Trinity, and it is hardly probable that the water of the Dallas wells will ever be exhausted by artificial means, provided too many wells are not drilled in close proximity, in which case the water would be drawn faster than it could percolate through the strata.

Negative or nonflowing wells in which the water rises near the surface, like the well at Sherman, can be obtained from these sands over most of the Black Prairie, their depth increasing to the eastward.

The value of these nonflowing wells should not be underestimated, for by simple mechanical means, as windmills and engines, no more expensive than the present cost of water, a supply of good, pure, nonmalarial water can be obtained for the villages and farms throughout the Black Prairie region, as well as sufficient in many places for garden irrigation.

The value of the Lower Cross Timber waters for irrigating purposes is a subject which promises great future results, especially in the extent of the Cross Timber proper, where the sandy soils, although at present devoted to unprofitable cotton-planting, are admirably suited for fruit-growing and will ultimately be entirely devoted to a more refined branch of agriculture.

The supply of underground water, although it will have to be raised by mechanical means, will be necessary to make this industry possible.

In the following chapters it will be seen that the other great sheets of artesian water are still below the Lower Cross Timber sands of the Dallas-Pottsboro area and will also supply water to this region.

THE WELLS OF THE FORT WORTH-WACO BELT OR TRINITY SYSTEM.

It must be evident that the wells west of the Lower Cross Timber sands south of where they disappear, as at Fort Worth and at Waco, can not possibly receive their waters from the same source as those of the Dallas-Pottsboro area, but must receive them from the higher region toward the west.

There are nearly 1,000 wells supplied from these sands in the belt of country between the main line of the Missouri, Kansas and Texas Railway, from Whitesboro to Taylor and Austin, and the Upper Cross Timbers, and the region is capable of supplying many thousand more without materially or perceptibly diminishing the supply, except in minor instances which I shall point out.

It is not everywhere that these wells can be obtained, however, as I shall point out in the following pages; laws of depth, occurrence, and distribution will be given which, if observed, will be of inestimable value to the people of this region.

The shallow flows of the Fort Worth system or wells of the Paluxy Sands supply.—The first successful wells in the Grand Prairie region were drilled at Fort Worth, in the river valley (altitude 490), and struck moderate flows of water at 263 feet in the western edge of the city and 484 feet below the highlands (altitude 662).

Over a hundred of these shallow wells were bored, and, as the stratum from which they were obtained, the Paluxy sands, was the thinnest of all the water-bearing sheets and had the smallest receiving area, these wells soon ceased to flow and it became necessary to pump them.

Before passing to the deeper supply beneath Fort Worth, it is important to add a few words concerning this first or shallower water derived from the Paluxy sands. Wells were drilled into this not only at Fort Worth, but as far north as Denton (altitude 628 feet) and as far east as Hearsts Fishing Lake, 10 miles southeast, developing an area of 30 miles square in which that water can be struck. The surface stratum in all these cases was the Fort Worth limestone of the Washita division, which is at least geologically lower by 1,000 feet than the Austin-Dallas chalk at Dallas and 600 feet lower than the same rock at Waco, and hence drills have that much less thickness in penetrating to it. The Eagle Ford clays here decrease in thickness southward and the Lower Cross Timber sands thin out at Waco, hence the difference between the chalk and Fort Worth beds there.

By the following section of a well at Kellers, northeast of Fort Worth (here given because it is the most complete record accessible), the exact strata penetrated will be seen:

		Feet.
Fort Worth Beds	Yellow clay	30
	Blue marl (soapstone)	2
	White limestone	49
	Blue marl	24
	White limestone	40
Caprina limestone	White limestone	95
Comanche Peak beds	Blue soapstone	42
	White limestone	52
	Blue soapstone	5
	White limestone	34
	Blue soapstone	5
	White limestone	5
	Blue soapstone	7
	Oyster-shell rock (Gryphæa)	13
Paluxy sand	Brown sand rock	13
	White sand rock	14
		400

It will be seen that the water is struck in the sands below the great Gryphæa (oyster) bed at the base of the Comanche Peak group, which are the Paluxy sands of the above section and are the same sands which can be seen outcropping between Cresson and the Brazos, at Weatherford, and elsewhere west of the city. By reference to the measured section of Comanche Peak, Hood County, it will also be seen that this is the first and thinnest sheet of water-bearing sands of the Trinity group.

The following sections will illustrate four other wells of Fort Worth:

	No. 1.	No. 2.	No. 3.	No. 4.
	Feet.	*Feet.*	*Feet.*	*Feet.*
Altitude of surface	629	5	490	662
Rock sheet at surface				
Limestone and marly clays of Fort Worth, the Washita division	115			
Duck Creek and Kiamitia	88			
Chalky limestone and Caprina limestone	95	370	155	
Marls of the Comanche group, Comanche Peak	150			
Oyster-shell rock (Gryphæa breccia)	13	22	25	
Paluxy sands, bearing best water	27	55	62	425
Total depth of first flow	488	447	242	425

Well No. 1 was bored deeper, striking water at 805, 1,030, 1,085 and 1,300 feet. At the latter depth it entered the impervious clays of the carboniferous system, with occasional sand, and is now nearly 4,000 feet in depth.

The first water was obtained in the Paluxy or highest sands of the great water-bearing series, the extent and distribution of which can be seen on the map. This is the sand into which the citizens of Weatherford dug for their surface water, and can be seen on the bluffs of the creeks around that city, and as far east as Aledo Station.

In the Waco wells a flow is usually found at 1,100 feet, which may also come from the Paluxy sands, but, owing to absence of sufficient data, this can not be verified, although the areal outcrop of Paluxy sands is quite large in Hood County, also in Bosque and Hamilton, where it can be recognized as the upland post-oak sandy region; its thickness decreases southward, and it is doubtful if it is valuable for water-bearing purposes there. Owing to its excessive mineral character and its relative depth, I am inclined to think the first flow at Waco is from the upper magnesian layers of the Glen Rose or alternating beds.

Wells have also been obtained from the Paluxy sands as follows:

Place.	Altitude.	Surface beds.	Depth.
	Feet.		*Feet.*
Denton	628	Denison beds	600
Hursts Lake	450	do	500
Packery, 3 miles north of Fort Worth	500	Basal Washita	
Shooneners, 3 miles west of Fort Worth		do	
Baur survey, 9 miles southwes; Van Ostrand survey, 5 miles northwest.		do	
Watson survey, 5 miles southeast		Denison	
Rightley's, 10 miles west of north		Basal Washita	
G. B. Stanley's survey, 4 miles northeast; Keller's, northeast.		do	

There is but little doubt that this water can be obtained over all the Grand Prairie in Tarrant County wherever the altitude is less than 900 feet; this includes all of the creek and river bottoms in the county, and all the upland prairie and Lower Cross Timbers in the eastern half of the county. The depth will not exceed 600 feet at the eastern edge of the area and decreases 28 feet in depth per mile to the westward.

These sands also underlie the Dallas Pottsboro area at a depth of about 600 feet below the bottom of the Lower Cross Timbers water, which thickness equals that of the Washita and Comanche Peak impervious beds.

Value of the Paluxy water for irrigation.—This water can be used for irrigating hundreds of small farms and gardens in the eastern edge of the Grand Prairie region, but improper application has created a strong prejudice against it. The mode of using has been to sprinkle the growing plants with water instead of soaking the soils. The chemical ingredients of the water are said to be injurious to the leaves, but Prof. J. P. Stelle, agricultural editor of the Fort Worth Gazette, has shown it is harmless and fertilizing if applied to the roots.

The value of these wells to the stock-raising industry, however, is incalculable, and their discovery and use to the region in which they occur has been many millions of dollars in value.

It would be improvident to stop a well in the Paluxy Sands, however, for, as will be shown in the succeeding pages, they are but the beginning of a much more abundant and valuable supply that everywhere underlies them.

THE DEEPER FLOWS OF THE FORT WORTH-WACO SYSTEM.

When it was known that Fort Worth's drills had only tapped the first sheet of the great series of water strata extending 700 feet deeper the rumor was spread and is still believed by many that Fort Worth's artesian supply is limited and decreasing. When Waco had demonstrated the existence of deeper beds and voluminous wells in the system, Fort Worth, with the wonderful enterprise characteristic of that city, began an experimental well on the highest hill in the city, which not only fully demonstrated the existence of at least far greater water strata, but went completely through the water-bearing series and penetrated over 2,300 feet of impervious clays underlying it.

In February, 1890, the city council contracted for the sinking of an experimental well, determining to fully test the possibilities of the artesian water supply for the city waterworks use. The experimental well was located at about the highest point in the city, the top of Tuckers Hill, 52 feet above the Main-street crossing of the Texas Pacific tracks and 42 feet above the court-house square.

In boring this well a fine stream of artesian water, which flows 170 gallons per minute with a pressure of 15 pounds per square inch, was struck at 900 feet. This was cased off and the boring continued to a depth of 1,035 feet, when a stream of 200 gallons per minute was struck, which flowed with a pressure of 21 pounds per square inch. This stream was in turn cased off, and the work proceeded until at 1,127 feet still another fine artesian vein was pierced. This flowed to the surface 245 gallons per minute with a pressure of 29 pounds to the square inch.

All of these flows could have been put together, when they would have discharged fully 500 gallons per minute, or 720,000 per day, and at a point 142 feet above the Trinity River. This last flow not having the pressure sufficient to carry it to a standpipe 100 feet high, was cased off, and the boring continued in search of a still stronger flow.

Flowing Wells at Waw, Texas.

his experimental well has now been drilled to nearly 2,800 feet in oth, and it is proposed to continue it to a limit of about 3,000 feet, we ieve, if more water is not reached short of that depth. Now, as a ult of this experimental work, three heavy veins of artesian water ve been located as underlying the city, the least of which will raise ter to a height of 40 feet above the highest point in the city, and the epest of which will raise water to a height of 61 feet above the highest int in the city. This remarkable discovery has been further demon- ated.

First, the Texas Brewery, whose location is 50 feet lower than Tuckers ll, sank their well to the first or top artesian vein and obtained a flow upwards of 240 gallons per minute, with a pressure which carries the ater to the top of their immense building 90 feet above the ground. ncouraged by this success, the packing-house company began a well their house on the north side at a point 120 feet lower than the top of ıckers Hill, and it has now been drilled through the first and second tesian veins, and it is flowing at a rate of over 800,000 gallons in venty-four hours. They will continue the well to and through the wer artesian vein, when the flow will (if the Tucker Hill discoveries old good for the north part of the city) be fully 1,500,000 gallons in venty-four hours. The packing-house well is undoubtedly now flowing ore water in twenty-four hours than any other artesian well in the tate of Texas by at least one-third, and when the third artesian vein reached it will be the "Jumbo," the geyser well of the State. The ty experiment has demonstrated that Fort Worth has the artesian ater in quantities sufficient to supply a city of 1,000,000 people should ccasion ever require it. Ten wells located down in the valley, above gh-water mark, will supply over 10,000,000 gallons of pure artesian ater each twenty-four hours, and the water is pure; there is no min- al of any kind in solution in it; it is as clear as a diamond, as pure melted snow. Surely if there is an artesian city in Texas, it is Fort orth.

While to Fort Worth's enterprise the credit is due for first discover- g the underground water supply of the Grand Prairie region, it was ne citizens of Waco who developed its greatest capacity, by first bor- g deep below the Paluxy sands into the great water-bearing sheets of ne Trinity sands.

Two years ago (1889) a water company of Waco* struck the first ıccessful well on the higher ground in the south of the city, striking everal flows of water, the volume of which was so great (estimated at rom 500,000 to 1,000,000 gallons per day) that it created great rejoic- g and has been the cause of untold value in the development and im- rovement of the industrial and hygienic conditions of that city.

The discovery of this flow immediately led to the drilling of other ells, and as a result the city and vicinity possesses numerous superb ells, flowing an aggregate of many million gallons per day, and sup- lying water not only for all public and domestic purposes, but power or various industries, such as clothing factories, wood-working ma- hinery, and irrigation.

The wells vary in altitude from 400 feet (Kellum's, north of the city) o 550 feet (Prather's, 6 miles southeast), and have an average depth of ,886 feet, or about 1,160 feet below the sea level. The water is hot, aving a temperature of 103°, and is soft and tasteless.

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*Waco, altitude 431-500, is situated on the banks of the Brazos River (altitude 400), nd south of the city the country rises to the general level of the Black Prairie. he surface, except where covered by terrace deposits of the rivers, is the Austin- allas chalk.

The success of these wells at Waco gave great impulse to artesian experimentation, and since their discovery flows have been struck in the same beds at Austin, Taylor, Belton, Temple, and Fort Worth, but of varying pressure, volume, and temperature, owing to difference in altitude and initial stratum.

The number and characteristics of these wells can best be presented by the following statement, furnished me by Maj. S. H. Pope, of the board of trade, and through the kindness of Mayor C. C. McCulloch:

WACO BOARD OF TRADE,
Waco, Tex., July 7, 1891.

DEAR SIR: Replying to your esteemed favor as regards the artesian wells in and around Waco, will say that there are now eleven overflowing and two approaching completion.

Seven of the flowing wells and one nearing completion, now about 1,700 feet deep, are owned by the Bell Water Company. One of the flowing wells and one nearing completion, now about 1,000 feet deep, are owned by the Waco Light and Power Company. The three remaining flowing wells belong one to each, respectively, to the estate of W. R. Kellum, deceased, William L. Prather, and Tom Padgett.

The altitude of the public square of Waco is 421 feet above sea level. The altitude, diameter, depth, estimated flow, temperature, and initial pressure per square foot of the several wells are as follows:

Name of well.	Altitude.	Diameter.	Depth.	Flow per diem.	Temperature.	Initial pressure.
	Feet.	*Inches.*	*Feet.*	*Gallons.*	° F.	*Pounds.*
The Moore Well	493	6	1,840	600,000	103	*65
The Bell Well †	500	6	1,820	500,000	102½	*60
Jumbo Well No. 1†	500	8	1,848	1,200,000	103	‡70
Jumbo Well, No. 2†	500	8	1,860	1,000,000	103	65
The Glenwood	495	8	1,860	1,000,000	103	*65
The Dickey Well	582	8	1,840	1,000,000	103	*60
The Bagby Well	475	8	1,845	1,000,000	103	*60
The Waco Light and Water Power Company Well	532	6	1,812	300,000	100	40
The Prather Well	655	6	1,607	500,000	97	‡40
The Kellum Well	420	6	1,776	1,000,000	103	‡70
The Padgett Well	485	6	1,886	1,000,000	....	‡72

* Estimated. † These three, the Bell, Jumbo No. 1 and No. 2, are 50 feet equidistant. ‡ Tested.

The foregoing statements of flow per diem (twenty-four hours) are estimates. An attempt was made to measure the flow of Jumbo No. 1, but it was unsuccessful. An expert, a member of the United States Artesian Survey Corps, who made the attempt and failed, estimated the flow at 1,000 gallons per minute. If this statement is correct the output per diem would be 1,440,000 gallons.

I have assumed the output of this well to be 1,200,000; with this as a basis the output of the other wells has been estimated. The pressure of the Jumbo, Prather, and Padgitt wells have been testified; the temperature of all has been ascertained by the thermometer.

The first well overflowed in March, 1889, and the last in May, 1891. Neither has affected the flow of the other, although 6 are located on Bell Hill and 3 on Dickey Hill. The distance between the Prather and Kellum wells is about 4 miles.

The analysis of the waters of the Bell well, made by the leading chemist of Chicago, in grains per United States gallon, is as follows: Silica, 1.3456; alumina, trace; iron sesquioxide, 1.493; sodium chloride, 6.0267; sodium potassium sulphates, 23.9583; calcium sulphate, .0000; sodium carbonate and bicarbonate, 20.6597; magnesian carbonate, .8432; calcium carbonate, 1.1579. Total solids by calculation, 53.8201. There is no appreciable difference in the taste of the waters of any of the wells; therefore we must assume that this one analysis covers all.

The average depth of the wells within the city limits is 1,842 feet. The average depth of all, including the Prather and the Kellum wells, is 1,814 feet. I inclose a written report of the Padgitt well, prepared by Mr. P. J. Fishback, the contractor. He is a practical well-borer and something of a geologist. I think this report can be received as a fair statement for all the wells in the city. I send by mail 5 bottles of sand passed through.

The water is soft, and is used for drinking, cooking, bathing, washing—in a word, for all domestic purposes. It is also used for sprinkling flowers and lawns. It has not been used extensively for irrigation, but so far has proved very healthful to all vegetation.

It is applied to motors of from 2 to 15 horse power. These motors run fans, printing presses, all the machinery of a coffin factory, with a daily capacity of 100 coffins; also a clothing factory of 250 sewing machines, cutters, and other necessary machines. I regret that I can not furnish you photographs of the interior factories. You have photos of the group of 3 wells.

I am, yours truly,

S. H. POPE,
Secretary.

The rock sheets passed through in boring these wells, from a section kindly furnished by Mr. Fishback, who kept an admirable record of the Padgitt well, are as follows:

Record of drilling in Padgitt artesian well, Waco, Tex.

1. Dark soil, changing to light, calcareous	feet..	18
2. Soft white limestone, "Austin-Dallas chalk"	do...	110
3. Blue shales, "joint clays"	do...	162
4. Light-brown, carbonaceous shales	do...	40

These shales gave a small quantity of petroleum. They slaked rapidly on exposure to air and water, and soon became fine mud. Walls of well caved badly in this stratum.

5. Brown calcareous marl	feet..	15
6. Blue shales, "joint clays"	do...	121
7. Brown, carbonaceous shales, lignitic in character	do...	60

These shales gave off a small quantity of petroleum. Walls of well caved badly in this stratum, necessitating the setting of 7⅝-inch casing just below, in stratum of marl.

8. Brown calcareous marl	feet..	38
The 7⅝-inch casing was set in this marl at	do...	536
9. Blue shales, "joint clays" (Washita)	do...	411
10. Brown carbonaceous shales, lignitic in character	do...	45

These shales gave a trace of petroleum. They caved badly, drilling proceeding through and beneath them with much difficulty.

11. Cream-colored, calcareous marl	feet..	156

Immediately under the last carbonaceous shale stratum and in the upper portion of this marl stratum, considerable water came in.

This water was highly charged with impurities of lime, sulphur, iron, and probably epsom salts. Water was not analyzed. The 5⅝-inch casing was extended to the bottom of this marl stratum to shut off this impure water, which was done, the hole being dry for the next 75 feet. The 5⅝-inch casing was set at 1,176 feet.

12. White limestones were occasionally interstratified with thin seams of blue shale, or light-colored calcareous marl (Washita and Comanche Peak),	feet.	554

From about 1,250 feet to 1,500 feet water came at different horizons, making an artesian flow of considerable volume; below 1,500 feet apparently no more water came in until the first water and sand were reached, at 1,782 feet.

13. Blue calcareous, silicious shales	feet..	30

These shales were of somewhat plastic natures, contained some lime, with also considerable proportion of very fine, light blue sand. This stratum would seem to mark the transition from shallower and more agitated waters, depositing sand, to deeper and more tranquil sea conditions, favorable to the growth of shellfish and the making of limestones.

14. Soft, very fine-grained, gray sandstone (Trinity)	feet..	15

This sand was seemingly dry, producing no apparent increase in the volume of upper water.

15. Red, plastic shale, local bed in Trinity	feet..	7
16. Soft, very fine-grained, light-gray sandstone		

This sand responded with water as soon as reached, and gave the first strong artesian flow proper from the well.

17. Blue shale, local bed in Trinity	feet..	5
18. Soft, very fine-grained, light-colored sandstone		

This sand largely increased the flow of water.

19. Blue, plastic shale, local bed in Trinity ....feet.. 8
20. Soft, very fine-grained, white sandstone ....do... 28

In this sand the largest volume of water was obtained, slightly increasing the pressure and temperature and nearly doubling the flow from the well.

21. Blue, plasic shale ....feet.. 5

The thickness of this stratum unknown. This shale was drilled into a depth of five feet, but the flow and pressure of water was so great that the sand pump would not descend through the lower flow of water, and, consequently, the sediment could not be removed from the bottom of the well below the horizon where the heavy flow of water came in, and drilling had to be suspended.

Further drilling could only be prosecuted by shutting out the flow of water by extending a string of casing to the bottom of the well and reducing the size of the well below that point.

Pressure of well ....pounds.. 72
Temperature ....° F.. 103¼
Volume, per diem (approximately) ....gallons.. 1,000,000
Total depth of well ....feet.. 1,866

Remarks.—While no opinions on matters of this nature can ever be accepted as absolutely correct until verified by the drill, yet from the grained texture, quality, and appearance of the sands, I am decidedly of the opinion that the bottom of the sandstone column has not yet been reached in the Waco wells, and that there is strong probability that other and coarser sands may be found still deeper. If found, they would give yet an increased volume of water, with also slight additional pressure and temperature.

Very respectfully,

P. J. Fishback,
Contractor.

Reviewing the foregoing section (the Padgitt well at Waco), the formations passed through are as follows:

Altitude.	Depth.	Thickness.	Remarks.
285–357	0–128	128	Austin chalk and residual soil.
357–79	564	436	3, 4, 5, 6, Eagle Ford clays, fish beds.
79 above to 631 below sea level.	962	398	8, 9, 10, various beds Washita division marly clays, with limestone.
636 to 1,255 below sea level	1, 250	....	First water near top of alternating beds.
	1, 742	778	11, 12. Caprina, Comanche Peak, Walnut clays, and alternating beds into Trinity.
1,353–3 below sea level	1, 838	98	13, 14, 15, 16, 17, 18, 19, 20, 21, Trinity sands, with its clay bands, 98 feet.
Total	....	1, 338	
Total thickness of water-bearing group.	....	538	

From a study of this section and a comparison with those of Dallas and Fort Worth it is evident that the total thickness is about the same as if the Dallas drill hole (Nos. 1–6 of the Waco) should be placed on top of the Fort Worth (Nos. 7–21), of the Waco section.

It will also be evident that neither the Lower Cross Timber sands, from which Dallas obtained her supply, or the Paluxy sand, which should be between Nos. 6 and 7 and Nos. 12 and 13, respectively, are sufficiently developed, if at all, to be noticeable, and that Waco draws her main supply from an entirely lower and different source, the 876 feet of strata below the horizon of the Paluxy sands, and especially the lowest 98 feet of sands. This, the greatest of the flows, is 1,278 feet below the bottom of the Dallas wells.

The following section, measured from the top of Comanche Peak to the Brazos River, where that stream has exposed by erosion the lower half of the rock of the Waco drill hole, will give a view of these water-bearing strata:

Section from Brazos River, altitude 755, at Granbury, to top of Comanche Peak Butte, altitude 1,250, showing detail of lower water-bearing beds of Comanche series.

	Feet.
7. Caprina—Hard, chalky limestone, character uniform throughout; fossil shell rudistes occurring very irregularly; forms caprock of mountain; impervious	33
6. Comanche Peak beds—Slightly softer chalky limestone; more variable in hardness than the Carpina, thus forming distinct benches; impervious	66
5. Gryphæa and Walnut beds—Hard limestone (small fossil; gryphæa pitcheri, above it)	3
Marls, calcareous, with Gryphæa	8
Local harder layer intervening	1
Marls with Gryphæa	4
Rough broken limestone	1
Marls, upper part chalky	15
Hard crystalline limestone walnut slabs, with Gryphæa, marly layers	4
Hard yellow limestone	1
Marly layer	5
Hard limestone flags, lower portion more fossiliferous and argillaceous and pervious to water	3
Marly layer	12
Marly layer	3½
Limestone slabs	1
B. Limestone slabs, compact and coarser	½
Marly layer	4
Limestone slabs	2
C. Marly layer	3
Compact magnesian limestone slabs	1
Marly layer	4
Hard white crystalline limestone makes decided bench	3
Marly layer	10
Gray, slightly argillaceous limestone	1
Marly layer	4
White broken limestone, fossiliferous	2
Three soft limestone layers, with intervening marls	6
White, evenly laminated limestone, with ferruginous segregations	1
Calcareous marl, changing gradually into harder limestone	8
Soft argillaceous limestone (pervious) surface	1
Angular, broken up with blocks, clays more argillaceous and marly at upper portion, basal portion more arenaceous and laminated	21
Rough, broken argillaceous limestone (porous)	2
Gryphæa marls and clays with white calcareous hardening	4
Marls	5
Massive breccia of Gryphæa	4
Marls with many Grypaea	15
Gryphæa	9
Hard Gryphæa layer	1
Marls	4
Local harder layer	1
Marls	3
Limestone with Gryphæas	4
Marls, Gryphæa and Exogyra texana	4
Local hard layer	1
Marls with Gryphæas	14
4. *Paluxy water sands.*—Forest clad, in portions somewhat calcareous but usually constant throughout	100
3. *Alternating or Glen Rose beds.*—Slightly fossiliferous above, sandy below	4
Hard magnesian limestone, few fossils, small, ferruginous segregations	4
Soft marl	10
Oyster beds	4
Marly beds	3
Hardened limestone layers	3
Marly beds	10
Caprotina, caprotina limestone; caprotina very abundant at base, upper portion less fossiliferous, rather variable lithologically	201
1. Sand, with some limestone and sandstone layers and calcareous nodular layers.	

Résumé of Comanche Peak sections.

		Feet.
4. Comanche Peak division, 220 feet	Caprotina limestone	33
	Comanche Peak chalk	90
	Walnut clays	32
	G. Pitcheri beds	56
3. Paluxy sands		100
2. Alternating or magnesian beds above Glen Rose horizon		175
3. Glen Rose or alternating beds and Trinity sands here pierced by drills at Glen Rose, about		300
Total thickness of water-bearing group		795

These basal sands are the great Trinity sands, the most extensive and porous water-bearing sheet in our country, except perhaps the Dakota sandstone in Dakota, while the alternating beds above them are full of small sandy layers, which in other artesian regions than this, where they are so overshadowed, would in themselves be esteemed of great importance, and which tend to increase the capacity of the wells bored through them. These alternating or Glen Rose beds (chalk, oölites, and sands) all possess great imbibing and transmitting powers, so that they increase the receiving area of the Trinity sands. This condition of the overlying beds is quite different from that of the Lower Cross Timber and Paluxy sands, each of which, it will be remembered, is overlaid immediately by a dense impervious clay layer.

The outcrop of catchment area of the water-bearing Trinity division (Trinity sands and alternating beds) constitutes the surface formation of a vast area in Montague, Wise, Parker, Hood, Erath, Somerville, Comanche, Brown, Mills, Lampasas, and Burnet counties north of the Colorado, having an outcrop covering a total area of many square miles. The water-bearing sheets of the Trinity group aggregrate from 538 feet, as at Waco, to 750 feet at Fort Worth, and underlie the whole of the Grand and Black prairies, an area of 78,000 square miles, becoming deeper relative to mean sea level at the rate of about 45 feet per mile to the eastward. This vast sheet of porous sand is thoroughly charged with water, and constitutes a great underground reservoir which holds in constant saturation at least many billion gallons of water, under strong hydrostatic pressure. The imbibing capacity of the Trinity sands is the maximum, owing to their angularity, coarseness, and purity, as can be seen by the rapid manner in which the sands imbibe the water.

These sands, from which Waco secures her water, are the same pack sands which furnish the ordinary well water in the town of Comanche (see profile 2). Twenty-two miles east at Dublin they have dipped beneath the surface 400 feet lower than the altitude of Comanche (altitude 1,000), and so on at Whitney, McGregor, and other places to Waco (altitude 421), where they are 2,400 feet lower than at Comanche, and at Marlin, on the east of the Black Prairie, they will be at least 3,000 feet.

Many other successful wells of the Waco type have been drilled, beginning in the Austin chalk horizon, as at Waco, or in the lower beds of the overlying Ponderosa marls at Temple and Taylor. The first well at Austin, drilled by the State in the capitol grounds, was stopped contrary to expert advice at the first weak flow, and is practically valueless. Two other wells north of the capitol, one at the State asylum and the other a private enterprise, were drilled into the deeper and to the greater flow, which, owing to the superior altitude of Austin, however, (some 150 feet above Waco) have not so great pressure.

These experimental wells, which form a continuous chain from Fort Worth to Austin, with the single exception of a few miles, leave the conclusion that the flow from the Trinity sands can be procured the entire distance, 180 miles, both in highlands and valleys, along the line of the Missouri Pacific road, and many miles on each side, at least as far west on the uplands as McGregor and Belton.

These wells also prove the great distribution and approximate uniformity of the underground sheet of Trinity sands, and the city of Dallas, which is situated like Waco and Austin, upon the chalk, instead of being content with the present supply, should bore to this greater flow.

THE WESTERN VALLEY WELLS OF THE GRAND PRAIRIE, OR THE SHALLOW WELLS OF THE TRINITY FLOW.

The western edge of the Grand Prairie, as has been explained, is cut across by its rivers at various intervals into deep drainage valleys, often 500 feet deep, which have left the remnant of the plateau standing as the flat-topped divides and mesas as so often seen in Hood, Erath, Comanche, Bosque, Hamilton, Coryell, and Lampasas counties. These uninhabited mesas are usually capped by the hard, sterile Caprina limestone, while the wide valleys between them are occupied by the fertile soils of the Walnut clays or rich stream alluvium, upon which is seated all the agricultural population of the region. In some of these valleys, as that of the Paluxy in Somerville County, the Trinity in Parker, and the Cowhouse in Lampasas, is a remarkable series of numerous shallow, flowing artesian wells, which have been inexpensively drilled by the farmers. This system of shallow wells has been principally developed in the valleys of the Paluxy and Squaw creeks, in Somerville County, and at Pidcock Ranch, 100 miles south, in Lampasas County.

In the former locality there are nearly 200 flowing wells, varying in depth from 30 to 300 feet, all of which begin in the various horizons of the Glen Rose, or Alternating Beds below the Paluxy sands and reach into the Trinity sands.

These wells can best be seen at Glen Rose, in the valley of Paluxy River, near where it flows into the Brazos, and from there into that stream some 20 miles to Bluff Dale, in Erath County. Nearly every farmer has one or more of these flowing wells, which are used for domestic purposes, stock-raising, and, in many cases, for irrigation. They vary in flow from 10 gallons per minute to 300, the smaller flows usually being from small bores and wells which do not reach the main supply. Nearly every house in the town of Glen Rose is supplied with one or more of these wells.

The water from the shallower wells is usually charged with mineral from the strata of the Glen Rose Beds. It has been the rule that this mineral water, which is the same struck in the Upper Beds of the whole Trinity division, as at Waco, Georgetown, Pidcock Ranch, can be cased off and a better flow obtained by going to the deeper and purer sands.

The finest of the wells seen by me was that at Mr. Lanham's farm, 6 miles west of Glen Rose, which flowed an 8-inch stream and about 350 gallons per minute, with which he abundantly irrigated about 50 acres of corn, cotton, and cane. I was informed upon good authority that there were many more farms irrigated in the same way. At Paluxy a similar well is used for irrigating a field of cotton. The total area of the Paluxy Valley from Bluff Dale to its mouth and of Squaw Creek, where this series of wells are obtainable, is over 200 square miles.

Over the southern drainage divide, in the valley of the Bosque River, a companion stream of the Paluxy, in Erath and Bosque counties, there is another similar area of shallow wells, as at Iredell and westward, having the characteristics of the Glen Rose group.

A similar area exists in the valley of the Leon, the next stream southward, from Gatesville westward. This stream valley should be thoroughly tested.

The next stream valley southward is the Cowhouse, and here again there has been in the vicinity of Pidcoke's ranch another great development similar to that around Glen Rose.

The following account from Mr. Roessler's excellent report will give a good idea of these wells:

> *Coryell County.*—W. H. Belcher, Pidcock Ranch post-office: In Cowhouse Valley, through which runs a small river, part in Hamilton County and part in Coryell County, are about 50 flowing wells. One well flows 50 gallons per minute, and it is about 320 feet deep.
>
> The other wells stop at the first stratum of flowing water. I believe if the wells were 100 feet deeper they all would run from 50 to 57 gallons per minute. These wells are all mineral water, but it has never been analyzed. None of these wells have more than 30 feet casing, and I expect that there is a great waste of water through the strata of these rocks. These wells can be drilled here for $200. Mine was the first drilled by insurance. Its depth is 290 feet; cost $500; capacity 2¼ gallons per minute, and is used for household purposes, live stock, and for irrigating a small garden, and is good for beets, potatoes, cabbage, corn, tomatoes, etc. It could be stored, but it is not. Altitude, 2,500 feet; rainfall about 30 or 35 inches. J. T. Meeks's well, 252 feet deep, cost $200; L. McCloskey, King post-office, well, 240 feet deep; cost $240; flow 2 gallons per minute; used for household purposes and live stock. Not good on vegetation. J. M. Davidson, Pecan Grove; flowing well, 220 feet deep; cost $233.60; flows one-eighth inch stream, soda and sulphur, good for family use, watering stock, and irrigating one-fourth acre of garden. Affects fine vegetables. Flowing wells are from 130 feet to 600 feet; rainfall about 35 or 36 inches, and beautiful showing for irrigation.

I have heard of no drilling in the upper valleys of the Lampasas, San Gabriel, and Colorado, but they present exactly similar conditions, as has been proven in part by the 500 to 1,000 foot wells procured in the lower valleys of the Lampasas and San Gabriel at Belton and Georgetown.

North of Glen Rose the continuity of these shallow conditions has been demonstrated at Springtown, in northern Parker County, where, according to Roessler, there are six or seven flowing wells within a radius of 2 miles at Springtown, Parker County, and this seems to be the only point in the county where such have been obtained. Water is generally obtained in ordinary wells at a depth of 18 to 40 feet. The rainfall is given as follows: 1878, 31.34 inches; 1879, 23.71 inches; 1881, 23.54 inches; generally sufficient to mature crops every year. The western half of the country is somewhat hilly, and is to a large extent covered with post-oak timber. The subsoil in many places is stiff red clay, and is usually found in such localities where it could be used in the construction of storage "tanks" or reservoirs from 1 to 10 acres in extent. Compared with irrigated lands the people of this county get a "half crop" from year to year. They could vastly improve on this by using the facilities they have at hand.

There is but little doubt that these wells can be procured in the valleys of the western edge of the Grand Prairie, in Parker County, west of the Grand Prairie escarpment, and in the valley of the Brazos near Granbury.

There are similar conditions in the lower valley of the Edwards Plateau, such as the Frio, New Braunfels and other rivers.

The total area developed of these valley wells of less than 500 feet depth is over 2,400 miles square. The system has only commenced its development.

Irrigation with these shallow wells has been demonstrated by farmers of the Paluxy Valley to be both practicable, inexpensive, and profitable.

In a former report I have shown that the region is subject to serious droughts, whlie the average yield is small, running from one-quarter to one-half a bale of cotton per acre. Most of this superb flow of water is not utilized for irrigation, because the methods and benefits of irrigation are not understood. Farmers, however, have attained good results from irrigation. Mr. William Lauham, who lives 6 miles west of Glen Rose, has an 8-inch well which flows about 400,000 gallons of freestone water per day. With this he abundantly irrigates 30 acres of land, utilizing the water only a few days in the year. Although he came to Texas from more humid regions and had never before seen irrigation, his success has been great. He has confined his efforts to the least profitable irrigable crops, corn, cotton, and Louisiana sugar cane, and has never manured or otherwise fertilized his land. The following table shows his experience:

Products.	Average yield without irrigation.	Yield of same land irrigated.		
		1888.	1889.	1890.
Corn .... bushels..	25	75	66	40
Seed cotton .... pounds..	200 to 500	2,200	3,000	4,000
Molasses of Louisiana or Ribbon cane .... gallons..	....	....	850	350

Several other experiments in irrigation in the same neighborhood have met with equally successful results. No one has irrigated alfalfa, clover, small grains, or small fruits, which are most susceptible to profitable irrigation.

At Paluxy village, 10 miles west, were two irrigated farms upon which cotton was growing two bales to an acre.

In general, however, the waste of this water is most unfortunate, for if properly used it would be of priceless value to the agricultural interests of Texas.

THE FIVE HUNDRED-FOOT TO ONE THOUSAND-FOOT WELLS OF THE TRINITY FLOW, OR THE MORGAN-GATESVILLE GROUP.

Still further eastward and down these valleys in the belt usually having a surface of the Morgan clays, there is another belt of wells which are deeper, owing to the accession of overlying strata layers and dip to the eastward. These are secured around Morgau, Meridian, Georgetown, Belton, and other places in a north and south belt, of the Grand Prairie, upon the outcrop of the Comanche Peak and Washita divisions, and the wells average from 500 to 1,200 feet deep. This belt includes the Fort Worth and Denton wells, those at Whitney, Georgetown, McGregor, and Belton, and especially fine flows have recently been struck at the last two places, both of which are situated upon or near the base of the Washita division (Nos. 8, 9, 10 of the Waco section). At McGregor the well is 1,200 feet deep and has the great flow of the Waco wells (19 miles east). The shallow Paluxy flow had been obtained here several years ago upon the farm of Col. W. P. Gaines. At Belton (altitude, 519), situated at the top of the Caprina limestone, a little lower geologically than Fort Worth or McGregor, two superb flows have been struck this year, concerning which Mr. Wilson T. Davidson, the young geologist of that city, has furnished me the following list:

Note on wells of Belton by Wilson Davidson.—There are two wells within this place, both drilled within the past twelve months, 1890-'91. One of these in the jail yard near the court-house (approximated altitude, 519), presents the following section, as furnished by the well-driller:

			Feet.
1.	Soft limestone	Comanche	25
	Blue marl or slate		300
2.	Blue limestone	Glen Rose	50
	White putty or mud		15
	White limestone (soft)		50
	Sand rock with iron pyrites (hard)		10
	Limestone		100
	White mud		25
	White limestone		250
	White mud		25
3.	Sandstone	Trinity	40
	Total		890

The flow is very strong, but as its amount had not been taken I could not get it.

The citizen well dug some months ago is 70 feet higher than this, and (according to Col. Denny) this one is approximately 70 feet less in depth.

The water in the county well is 30° F. warmer than the well dug last march (Col. Denny).

As to the flow of the new artesian well—by making repeated experiments with a large barrel, and stop watch, I found it to be 1,002,040 gallons per day. The barrel was filled in five seconds every time. Of course this is not exactly correct, but approximate. I also wish to state that the water sand is 35 feet in thickness, same as in the other well.

The Fort Worth drills commence in 8 and penetrate to 12, to reach the Paluxy water, and from thence downward the section is similar to Waco.

Owing to the lower geological horizon of all these places, they are 500 feet nearer to the great water sheets than the Austin-Waco belt, by the absence of thickness of the Austin chalk in part and the Eagle Ford clays (the Lower Cross Timber sands missing at Waco).

THE LIMITS OF THE FORT WORTH-WACO SYSTEM.

It requires but a simple calculation of dip and altitude to see that th inclination of the lowest water-bearing sheets will carry them to a depth beyond practical reach (2,500–3,000) for economic use. This limit, if we estimate the thickness of the rock sheets, will be found in the eastern belt of the Black Prairie region, between the great Atlantic Timber belt and the line of outcrop of the Austin-Dallas chalk. At Thorndale (altitude, 450) and Terrel (altitude, 425–514) situated upon a north and south line, some 200 miles apart, upon the eastern margin of the Black Prairie, at the top of the Ponderosa marls, over 2,000 feet have been drilled into these marls without reaching the Austin chalk, and it is probable that the same conditions prevail every foot of the way between them, as illustrated about half way, at Marlin (altitude 394) Falls County, where the drill is now 1,600 feet in the marls.* Wells at Kaufman, Corsicana,

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* The first or Paluxy flow has since been struck at 2,100 feet in the Marlin well.

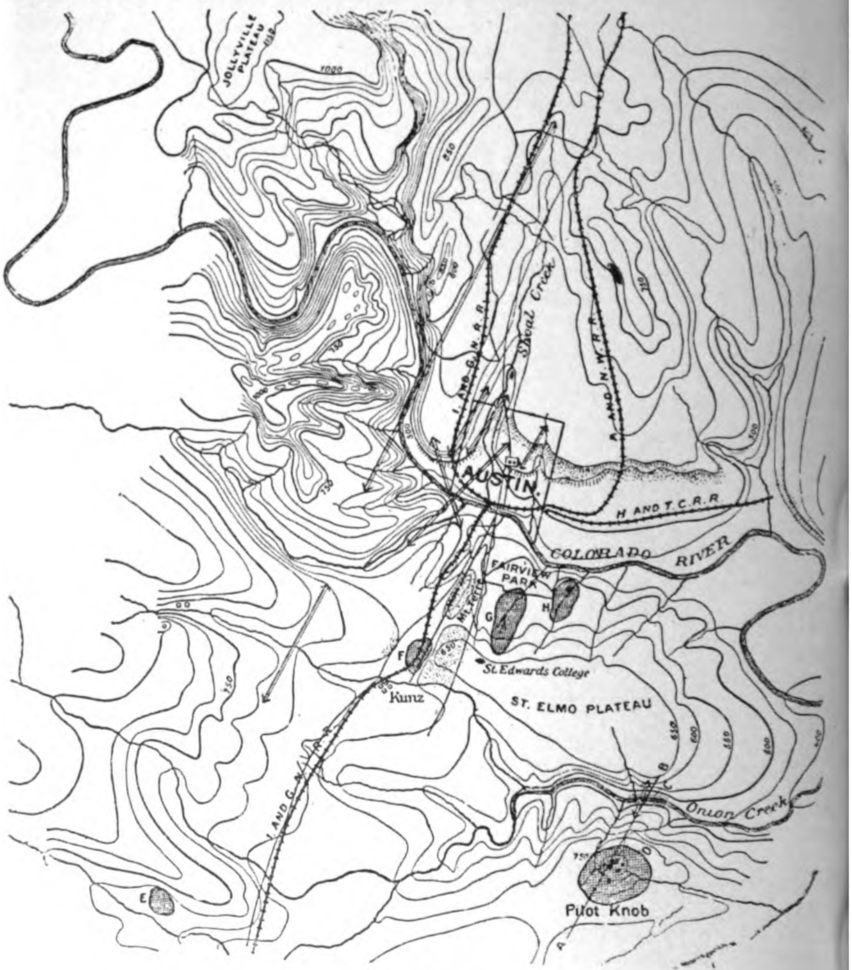

FIG. 8.

MAP OF AUSTIN, TEXAS, AND VICINITY, SHOWING OUTCROPS OF IGNEOUS ROCK (SHADED AREAS) THROUGH THE WATER-BEARING STRATA OF THE GRAND AND BLACK PRAIRIES AND BREAKING THEIR CONTINUITY.

and all other intervening points will no doubt meet with similar experiments.

This belt is at least 2,800 feet geologically above the face of Trinity sands, and 1,800 above the Lower Cross Timber sands north of the latitude of Hillsboro.

The only portion of the Grand and Black Prairie regions, where this water can not be made to flow, between the Colorado and the latitude of Denton, is on the tops and slopes of the high mesas ("mountains" in local parlance) which form the high divides of the stream valleys of the western half of the Grand Prairie, and are higher in altitude than the receiving area of the Upper Cross Timbers.

ARTESIAN FAILURES IN THE GRAND AND BLACK PRAIRIE REGIONS.

The proportion of failures in this region north of San Antonio have been remarkably small. Of the numerous wells drilled, only a few have been unsuccessful, and the latter, except in two instances, were not drilled down to the water-bearing sands. In but one instance has a well which penetrated to the Trinity sands failed to secure a rise of water, and this was at Taylor, where the second well drilled, in less than a mile from a most magnificent flow, was utterly dry, the Trinity sand especially so. I can offer no explanation of this, except that there was local imperviousness or perhaps certain conditions of faulting and slipping in the strata that cut off the sands from the water. At Thorndale, Marlin, and Terrel the wells were not drilled to the water. At Kerrville granite was struck at 700 feet. At Cable's Ranch, 12 miles west of San Antonio, 2,200 feet of the Comanche series were unsuccessfully penetrated.

Negative or non-flowing wells.—At Rome, Wise County, a well struck the water, but it failed to flow to the surface, because Rome is higher in altitude than the receiving area. The water rose sufficiently high to be pumped and is of great value. At the old well at Denison the water in a 1,200-foot well failed to flow for the same reason, that city having some 200 feet higher than the Trinity sands outcropping at Red River, at the great bluff below Preston. The value of nonflowing wells, however, should not be underestimated. Where the water rises to within pumping distance it is far more valuable than the surface water, on account of its freedom from organic matter. They can be obtained nearly everywhere in the region.

I have mentioned, p. —, a great fault or break in the strata from Marietta southwestward (followed by Red River from Preston to 7 miles east of Denison) towards Roxton and beyond, in Lamar County. By this great fracture the whole region of the Grand Prairie and water-bearing Trinity sands in Indian Territory has dropped below the altitude of the Red River tier of counties, so that there is no hydrostatic pressure to force it up south of the fault on the Texas side, as proven by the borings at Denison and Paris. On the Indian Territory side, however, it is different, and magnificent flows should be obtained from the Paluxy and Trinity sands in this region, under exactly the same conditions as previously explained of the Lower Cross Timber sands.

CONCLUSIONS AND SUMMARY OF THE ARTESIAN CONDITIONS OF THE BLACK AND GRAND PRAIRIE REGIONS.

It is now evident that this region of Texas is underlaid by several vast sheets of water-bearing strata occurring at various intervals apart. The lowest and most valuable of these are the Trinity or Upper Cross

Timber sands, which underlie every foot of the region and are the source of a probably inexhaustible supply. This is the lowest sheet of a group of water bearing sands at the base of the Lower Cretaceous or Comanche series, the highest of which, some 750 feet above it, is the Paluxy sands, which afford but a feeble flow and only extend under the region north of the Lampasas.

From 1,500 to 1,700 feet above the Trinity sands and 800 to 1,000 above the Paluxy beds is another group of water-bearing sheets, which outcrop in the Lower Cross Timbers, from which Dallas and Pottsboro receive their supplies. This sheet underlies only the Black Prairie region, and, while of great value, is not to be compared with the Trinity beds, which can always be struck by boring through it.

Having presented the geological character of the possible areas for securing water in the Black and Grand Prairie regions, I propose to show by the application of a simple rule how the approximate depth of the water sheets can be determined at any point. By drawing north and south lines through points of equal depth relative to mean sea level it may be granted that artesian flows can be obtained at any intervening point of that line, provided the surface altitudes are also similar. Thus a line drawn through Pidcock Ranch, Glen Rose, and Springtown will show that all along that line, at points of the same altitude, the Trinity water can be obtained at a less depth than 500 feet; A similar line through Georgetown, Belton, and Gatesville will cross all points where the 500 to 1,000 foot wells from the Trinity sands will flow; one through McGregor, Whitney, and Fort Worth will show the points where the 1,200-foot depth can be obtained; one through Austin, Waco, Taylor, and Dallas, the 1,500 to 2,000 foot depth, and so on to the east. Furthermore, the depth of the artesian flows can be approximately prognosticated by a knowledge of the geological horizon outcropping at the surface. For instance, in the region where the Glen Rose beds outcrop the basal Trinity water sheet is not over 500 feet deep; where the Comanche Peak division occupy the surface the Paluxy sands water is from 0 to 300 feet, and the basal Trinity or Jumbo flow from 500 to 1,000 feet; where the Fort Worth beds occupy the surface, the depth of the Jumbo flow is from 1,000 to 1,500 feet; in the region of the Lower Cross Timbers and Eagle Ford Prairies it is from 1,500 to 1,800, and along the line of the Dallas-Austin Chalk from 1,600 to 2,400, the depth increasing to the northward.

The depth of these wells depends upon their altitude and distance from the outcrop of the receiving area. This depth increases relative to mean sea level at the average rate of 30 feet per mile, and hence adjacent to the receiving area are shallow flows from 30 to 300 feet as at Glen Rose, Springtown, and Pidcock Ranch, while upon the eastern edge of the Black Prairie, as at Thorndale, Kaufman, Corsicana, and Terrell, these sands are over 3,000 feet in depth.

The pressure is inversely proportionate to the altitude of the wells, being greater where the point of overflow is lowest. It is owing to Waco's situation in the deep valley of the Brazos that her wells have such magnificent pressure, and it is owing to Dublin's very high altitude that her wells have a small pressure.

It has been a question with most well-drillers where to stop their drills. Many have the theory that the deeper the drill penetrates the strata the more will be the water obtained, while others, content to let well enough alone, have ceased drilling at the first flow of water obtained. Both of these hypotheses have to a certain extent been right, yet in their application they have often been wrong. The only sure rule is to have a knowledge of the succession of the rock sheets and to govern the depth of the drill holes accordingly. The following rules, however, may be considered of value in determining the question:

1. If water is struck in the Lower Cross Timber sands the drill should continue at least 200 feet into the Fort Worth limestones, in order to obtain the benefit of all the flows of the sands. Below these the drill must go from 600 to 700 feet in order to reach the Paluxy sands, and from 600 to 700 feet below these to the main or Jumbo supply of the basal Trinity sands.

2. When the greenish-red clays of the Carboniferous system below the basal Trinity sands are reached, it is hopeless and useless to drill farther, as shown by the deep drilling at Fort Worth and at Cisco.

3. When the feeble mineral flows of the Paluxy and Upper Trinity are reached, the drill should by all means be continued from 200 to 300 feet deeper to the basal or Jumbo flow. Many of the earlier wells dug at Fort Worth, Morgan, Meridian, and Glen Rose should be deepened. (See profiles.)

THE ARTESIAN CONDITION OF THE BLACK AND GRAND PRAIRIES SOUTH OF THE COLORADO.

There are many reasons for separating the prairie regions south of the Colorado from those north of it. The chief of these is the great Balcones fault or fracture, which extends from north of Austin to beyond Del Rio, by which the continuity and arrangement of the stratification is greatly broken, the strata of the Grand Prairie or Edwards Plateau becoming more horizontal, while the Black Prairie has dropped down and is covered by the great La Fayette gravel sheet which extends along the Atlantic and Gulf seaboard and greatly changes the surface aspects of the region. Again, the great fault line is accompanied by a remarkable series of ancient volcanic necks of black basaltic rocks, which break through the water strata. For these I have proposed the name of Shumard Knobs.* (Fig. 8.)

These ancient volcanic rocks appear in upward of twenty places in the counties of Travis, Hays, Blanco, Comal, Kendall, Medina, Uvalde, Edwards, and Kenny.

Owing to their pressure it is impossible to predict the continuity of any area of flowing wells in the region, although the latter are numerous and abundant, while the great artesian springs here attain their greatest development.

The presence of these great masses of impervious igneous rock certainly render the certainty of artesian experimentation doubtful south of the Colorado and east of the International road in Travis County, where they cross from the Grand into the Black Prairie region. South of that point, along the International road to San Antonio, wells ought to be secured at most places within 40 or 50 miles of the escarpment. At San Antonio, as more fully treated in the chapter on the Rio Grande embayment, wells have been obtained and great abundance of flowing water, oil, gas, or all.

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* See American Geologist, January, February, 1890. A typical one, Pilot Knob, more fully described in a recent paper. See "Pilot Knob," American Geologist, 1891.

WATER CONDITIONS OF THE EDWARDS PLATEAU.

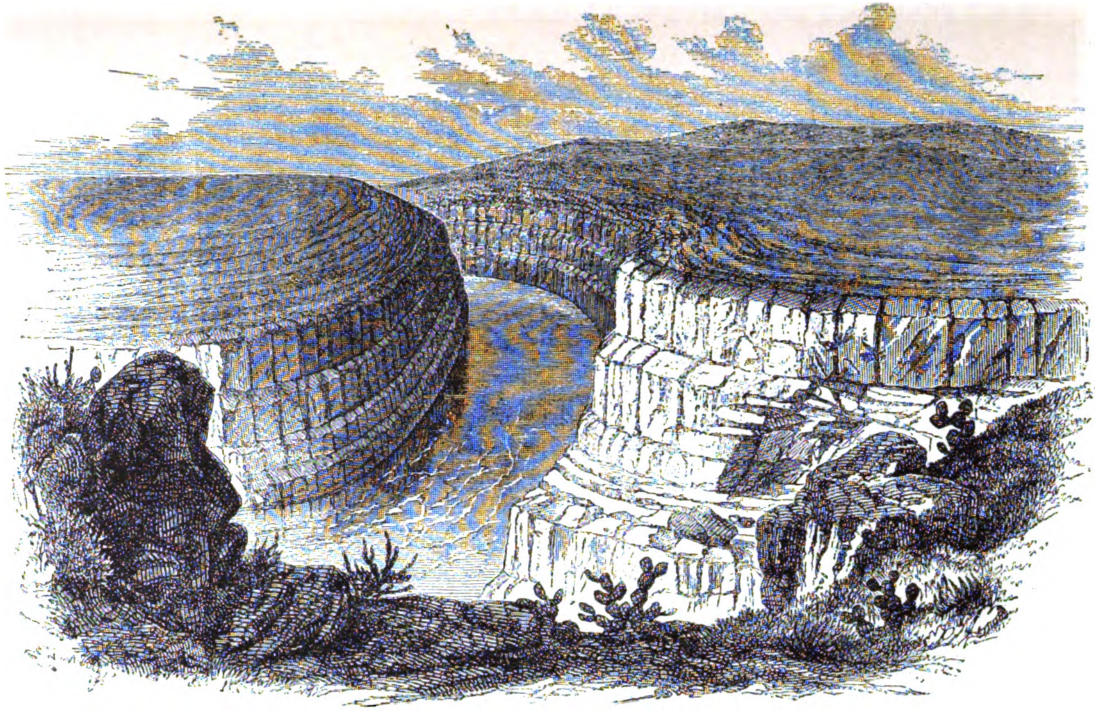
(See Plate II and Fig. 9.)

In the general description of the Kerrville plateau or southern division of the Grand Prairie, I have explained how it and its northward continuation—the Llano Estacado—forms a great elongated mesa or table-land, the northern half of which is covered by the great sheet of Tertiary strata of the Llano Estacado beds. The mass of the Edwards Plateau is mostly composed of spongy strata of the Glen Rose and Trinity beds, capped on the summits by the impervious Caprina limestone. By this arrangement, while the summits are dry, the whole mass of the interior and base of this immense mesa is charged with water like a sponge, which flows out at stream level on nearly every side and feeds all the streams south of the Colorado, as the Concho, San Saba, Llano, Pedernalis, Comal, Gaudalupe, Medina, Frio, Merces, and Devils rivers. These escarpment springs are often of great volume, like those of the Concho in Tom Green and adjacent counties, and all receive their supply from the earth water of the great mesa flowing out at the line of stream level, and never from the escarpment face or bluff. These characteristic springs can well be represented by placing a large sponge on a marble-top table and placing on top of the sponge a perforated sheet iron or grating. The grating will be similar to the jointed and fractured limestone cap of the Edwards Plateau, whose water percolates downward into the sponge and prevents it from evaporating. The sponge will be analogous to the Glen Rose and Trinity sands, capable of holding much water in saturation, even when dry around its edges. The marble represents either the impervious Bed beds floor or the line of complete saturation in the Trinity beds themselves, which in either case will prevent the farther downward percolation of water, and, hence, by its own gravity it will flow or sipe out at the line of the lowest relative level, which is usually the stream beds. This is exactly the case of the springs of the great Edwards Plateau. The surface is dry and poorly adapted to agriculture, like the mountain tops (mesa) of the main Grand Prairie region, and has very little population. The deep canyons cut in to the spongy Glen Rose and Trinity beds form the sides of this mesa and usually have water and numerous springs, and in them is situated all the agricultural areas, but they do not constitute one per cent of the vast area for which the springs might be available.

The canyon springs in the eastern edge of the plateau, where there is more rainfall, are among the picturesque features of Texas, especially the valleys of the Guadalupe and Concho, and present unusually fine conditions for irrigation of the farming lands which border them.

The springs of this region are too numerous to give in detail, but the principal ones, beginning on the north, are the Big Springs of Howard County (in the transitional region between the Llano Estacado and the Edwards Plateau) which were admirably described by Mr. F. R. Roesseler in the report frequently cited in this work. These springs flow from the Trinity sands, as since determined by specimens and sections furnished by Mr. Roessler.

Proceeding southward across the drainage divides (spurs of the main plateau) magnificent seepage springs of great volume are met in the valleys of the various branches of the Concho River, which have furnished water for irrigation in the Tom Green country for many years. These all break out from the Trinity sands and conglomerate. Continuing eastward, the next greatest springs are met in the Menard country,



Cañon of the Rio Grande, 105 miles above the Mouth of the Rio Pecos.
Showing structure of the Edwards Plateau. [Report of Major Emory, U. S. A., 1856.]

which flow as follows: McKavett, Block Springs, 300 cubic feet; Clear Springs, 1,200; Coglan Springs, 100; Elm Springs, 75. These springs originate the San Saba River; continuing around the eastern and southern border they increase in number until the Nueces is passed. In the Pecos Valley, Howard Springs, in Crockett County, are the last of the series of springs which drain the base of the Edwards Plateau.

On the surface of the Edwards Plateau water is reached only by deep wells from 3 to 500 feet in Val Verde County, which penetrate to the Trinity beds. These wells and their depths are given in the accompanying table. All experiments thus far have failed to reveal artesian conditions on this plateau from San Antonio to the Canadian, but this experimentation has been too limited to warrant any negative conclusions. In general these water conditions are of the same category as those discussed in the chapter on the Llano Estacado.

Non-flowing wells owned by the New York and Texas Land Company (Limited) in Kinney and Val Verde counties.

No. 1.—263 feet deep, 120 feet of water, 3 miles N. of Brackett.
No. 2.—257½ feet deep, 80 feet of water, about 5 miles N. 35° E. from Brackett.
No. 3.—274 feet deep, depth of water not given, 8 miles N. of Brackett.
No. 4.—299½ feet deep, 175 feet of water, about 10 miles N. 22° E. of Brackett.
No. 5.—378 feet deep, plenty of water, about 5½ miles N. 71° E. from Brackett.
No. 6.—289 feet deep, 130 feet of water, about 7 miles N. 49° E. from Brackett.
No. 7.—237 feet deep, about 9 miles N. 57° E. from Brackett.
No. 8.—150 feet deep, plenty of water, about 7 miles N. 68° E. from Brackett.

LINDHEIM PASTURE.

No. 1.—148 feet deep, plenty of water, about 10 miles N. 70° E. of Del Rio.
No. 2.—158 feet deep, about 7 miles N. 85° E. from Del Rio.

M'LYMAN PASTURE.

No. 3.—80 feet deep, 20 feet of water, about 16 miles N. 37° W. of Brackett.
No. 4.—65 feet deep, 25 feet of water, about 11 miles N. 22° W. of Brackett.

STANDARD PASTURE.

No. 1.—222 feet, 130 feet of water, about 13 miles N. 62° E. from Del Rio.
No. 2.—186 feet deep, 80 feet of water, about 16 miles N. 63° E. of Del Rio.

CROWL PASTURE.

There is one well on this pasture 85 feet deep, 30 feet of water, about 5 miles N. 60° E. of Del Rio.

UTILIZATION OF THE ARTESIAN WATERS OF THE BLACK AND GRAND PRAIRIE.

It is hardly necessary to dwell upon the need and value of water to the fertile region in which it has been obtained. A good water supply is the foundation of every civilization, and man's prosperity is usually proportionate to its abundance and purity.

In this special region the very qualities which make the soil rich have made the surface waters scarce, often impure, and more or less defiled by invisible germs of disease and malaria, the only afflictions with which this otherwise most healthy country is troubled. The city populations were especially restricted and inconvenienced by the lack of pure and abundant water supplies. Within the past few years all of this has been changed, and now we see the cities of Houston, Waco, Austin, San

Antonio, Fort Worth, Belton, Temple, Dallas, Denison, Denton, and Sherman (the latter a negative well) all drawing more or less abundant supply from underground sources, while hundreds of farms are annually supplied—giving increased value and new life to those places and an incalculable influence upon the material prosperity. Several of the large charitable and correctional institutions have also been supplied with this water, as the State insane asylums at Austin and San Antonio and the Reformatory at Gatesville.

In addition to the value of certain of these waters for their purity, certain others, as those from the Upper Glen Rose beds, at Georgetown, Waco, Pidcoke's ranche, Groome's well at Austin, and elsewhere, have superior medicinal virtues, resembling the celebrated Spas of Germany, which are found in somewhat similar rocks. These wells are of incalculable worth to the malarial region of the timbered coastal plain of east Texas, Arkansas, and Louisiana, and will undoubtedly be of great service to the people thereof, when they learn to appreciate them. The hygienic aspect of these waters, both the pure and the medicinal, will also prove of great value to the live-stock interests.

The industrial uses to which these waters are at present put are many. At Waco hundreds of sewing machines in clothing factories, electric motors, wood-working machinery, and other small industries are run by the pressure of wells, without wasting the water, by the use of small and powerful California wheels. When the high cost of fuel in Texas is considered, this use of artesian water becomes a most important factor.

The greatest use of this water at present is the fact that it brings to hitherto poorly watered farming and grazing lands an abundant supply of water for domestic and stock purposes, making small farms of 100 acres or less possible, where until recently subdivisions of large bodies of land or ranches were impossible, and, even in the rich black prairies around Waco, only large plantations could exist, each controlling a few surface wells or water holes from which the tenants or renters dragged for miles the dirty water in barrels on clumsy sleds, while in time of drought there have been failures of even the domestic water supply for large districts.

This condition has already changed, and Prather's well, for instance, on a farm south of Waco, alone furnishes more water than the entire surface supply of McLennan County, except the Brazos River, has hitherto afforded.

I drove during the great drought of 1877 from Decatur to Fort Worth, over a rich grass-clad region, without being able to secure a drop of water for myself or team the entire distance, while dozens of suffering teamsters were begging and trying to buy water from the owners of the few and all but exhausted surface wells along the way. With the knowledge now before us, every foot of that vast area of the Grand Prairie, being underlaid by water, could be cut into forty-acre tracts, upon each of which, if flowing water could not be obtained, magnificent negative wells rising nearly to the surface could be obtained, furnishing an abundance of waters unaffected by drought.

Irrigation of the Grand and Black Prairie region.—It is not the object of my report to discuss methods of irrigation, but to show the amount and availability of the water.

The rainfall of the northeastern portion of the Black Prairie region, (the portion where artesian wells are least possible) is abundant for all plantation crops, which seldom suffer there for water. The remainder of the region is more or less subject to drouth at intervals from five to two years as we go eastward. All portions are subject to long, dry periods annually (usually in the autumn, after the corn and cotton has been laid by), during which gardens and fruits suffer greatly.

It is not my intention to convey the idea that the Black Prairie region is subject to drought; for crops of corn and cotton are often rich and abundant, but all admit that it has seasons of rain and drought, and that, if rich now, it could be made immensely richer by irrigation, and all the fruits and vegetables now imported from the irrigated lands of Utah and California could be produced at home.

The value of these wells for irrigation has been demonstrated by the modest farmers of the Paluxy valley, who by their own humble methods and without previous knowledge of the subject are now quadrupling the yield of cotton and grain. A farmer at Paluxy stated to me that his 10 acres of cotton, yielding nearly two bales of 500 pounds each to the acre, was far more profitable and easily worked than 100 acres which he had until recently cultivated in Alabama.

Irrigation from the artesian well is at present successfully practiced in the Paluxy region, and the largest and most prosperous city in Texas, San Antonio, is built upon and about an irrigation enterprise, which has most profitably and successfully utilized their underground waters for nearly 300 years, affording occupation for all the mission settlements in the past, supporting hundreds of gardens at present and destined to be of great value in the future.

Every drop of water from these springs and wells can be utilized for irrigation, and when the people of the region appreciate the fact that each gallon of water has a specific value in agriculture, as has a pound of coal in industrial enterprise, not one drop of this water will be allowed to escape unutilized, and the agricultural wealth will be enormously increased.

IV.

THE ARTESIAN SYSTEM OF THE RIO GRANDE EMBAYMENT.

I have explained on a previous page how the features of the Coastal plain changed south of the Colorado or Guadalupe and the great Austin-Del Rio escarpment into a more arid and generally different region. This includes the continuation of the Coastal prairie, the Washington prairie, the Timber belt, and of the Black prairie, and all the Rio Grande counties as far west as Val Verde, all Maverick, Encinal, Duvall, Nueces, Webb, Dimmitt, La Salle, Zavalla, Frio, Atascosa, Karnes, Goliad, Refugio, Live Oak, San Patricio, Wilson, and Aransas, and the southern or eastern portion of Uvalde, Medina, Bexar, and Guadalupe.

The ninety-seventh meridian, which is accepted as the western limit of reliable rainfall, intercepts the gulf at Aransas Pass, the eastern limit of this region, and if reports be true it certainly is in its lower part at least, one of the arid portions of Texas, a drought of over eighteen months' duration having been recently reported from Hidalgo within 100 miles of the coast. The rainfall however is much greater towards its interior margin, San Antonio, to Del Rio, where the drought has not extended. This region is in many respects the least studied geologically in Texas.

Its predominant and topographic feature is its generally low altitude; the contour or line of equal altitude (of 600 feet) which marks its western margin makes a great deflection westward along the escarpment of the Edwards Plateau, up the Rio Grande to Eagle Pass, thence back towards the coast on the Mexican side, and constitutes a great indentation, as if it had been a bay of the gulf which covered the region in comparatively recent geologic time. This is further proved by the extensive deposits of sand, gravel, and conglomerate that mark its interior margin, indicative of a late sea level, and remain in places over the whole area, but greatly divided by a still more restricted and recent event to be seen nearer the Rio Grande Valley.

I am inclined to believe this gravel sedimentation is the interior margin of the formation of the Fayette prairies.

The interior margin of this débris, visible from San Antonio to Uvalde, is only a thin inconspicuous sheet and bears no relation to the artesian problems.

The fundamental structure underlying these surface sheets in portions of the coastal incline is the system of rock sheets from the Eagle Ford shales (bordering the escarpment from San Antonio to Uvalde) on its interior margin to the coastal clays and prairies at the coast, with slight variations from the same beds seen in Texas north of the Guadalupe. This includes a great thickness of alternations of porous and imporous beds, many of which are artesian water reservoirs. The San Antonio water strata are the lowest geologically of these water-bearing beds. Succeeding the chalks and clays which overlie them is a great development of sands and sandstones in the glauconitic division of the Upper Cretaceous and Eocene, which here is entirely different (owing to the different conditions of original sedimentation in this Rio Grande embayment), from the Arkansas-New Jersey development. These, for which I have proposed the name of the Eagle Pass beds, outcrop from west of Eagle Pass to Webb County line along the Rio Grande, and occur all over the embayment as far south as the Santa Rosa Mountains in Coahuila. Succeeding these are various beds of the Eo-Lignitic Washington (Miocene) and coast prairies, in all of which wells have been found.

This region, as a whole, has not been prospected for water in many places, and in most of the counties, especially those east of the International and south of the San Antonio and Corpus Christi roads, wells have not been drilled.

In most of the instances where drillings were made the results were successful and water was obtained at less than 500 feet in instances, and in no case has a depth of 1,000 feet been attained.

From the results so far recorded, mostly in Mr. Roessler's paper, it may be safely said, that at least four well-defined water areas have been penetrated in this area, to wit, commencing with the lowest as follows:

1. The San Antonio or Black Prairie system.
2. The Eagle Pass beds.
3. The Carrisso sandstone of Owen's, in Dimmit and Uvalde counties (of Laramie or Eocene Age).
4. The Eo-Lignitic sands.
5. The Washington sands or Galveston-Houston coastal system.

The wells of San Antonio are being bored so rapidly and successfully that their number can not be given. They often flow oil and gas (from the Eagle Ford shales as at Waco), but water is reached at a depth of from 600 to 1,000 feet in a hard sandstone, which, although not proved, is apparently the Lower Cross Timber sands, which have no real outcrop, owing to the great fault to the west of the city.

A section of the earliest of these wells shows:

	Feet.
3. Soil, clay, and gravel of the Quaternary period	36
2. Blue clay soapstone and black (oleaginous) shale (Fishbeds or Eagle Ford shales)	610
1. A very hard sandstone with strong flow of water, the horizon of which has not been determined	5
Total	651

In one well, 4 miles south of the city, this sandstone was penetrated for 75 feet.

The field of these wells around San Antonio has been explored for 10 miles eastward with great success. Twelve miles west of the city, at Heliotes, where the Edward plateau sets in, the entirely different rocks of the Comanche series were passed through, and a drill penetrated 2,000 feet, at Mr. Cable's ranche, without getting a flow, indicating a different condition. The country similar to San Antonio east of the Balcones fault should be explored as far west as the Austin chalk and fish beds extend (to Uvalde at least), and wells will probably be found which will be of inestimable value to that region.

There is every reason to suppose that these wells can be procured at many places, most places, in fact, from San Antonio westward, between the Southern Pacific and the "mountains" (Balcones escarpment) as far west as the Nueces, where several small shallow wells have been already obtained in Uvalde County. At Spofford Junction a well was bored 1,800 feet without striking water or getting below the Denison clays, which would indicate that at and west of that place the favorable conditions had ceased for procuring water from the beds of the Cretaceous.

At Del Rio, still westward, where the greatest of artesian springs occurs, the surface strata, Washita and Denison beds, are 1,800 feet lower geologically than at Spofford, and a weak flow of very poor artesian water was obtained at less than 1,000 feet.

The Black Prairie has little width in this region, but is overlapped coastward by great deposits of sandy strata belonging to the Upper Cretaceous and later periods.

The source of the Eagle Pass wells is undoubtedly the sandstones of the Eagle Pass beds, the oil and gas being derived from the lignites which they contain. Inasmuch as these beds underlie all the great basin on both sides of the Rio Grande, from Eagle Pass to near Laredo, and the general inclination is towards the river, the region is worthy of further prospecting.

At Carrizo Springs, in Dimmit County, and westward, there is a great sandstone deposit beneath the surface which has been named the Carrizo sands by Mr. J. Owen, the excellent geologist of Eagle Pass. (See preliminary report of the Texas State Survey.)

This sandstone has a wide outcrop in western Dimmit, southern Uvalde, and northern Nueces counties, surmounting the Eagle Pass beds. Several fine wells have been procured from the Carrizo sands, which have been reported by Mr. Roessler.

The extent and capacity of the Carrizo sands is yet to be determined, and there is little doubt but they will prove a most profitable and extensive artesian area, in the counties of Webb and Dimmit, and the region should be most thoroughly prospected.

The Atascosa wells, or Eo-Lignitic sands. At Pleasanton (altitude, 300), in Atascosa County, a well was secured at 108 feet. Not having been able to visit this point, I can only base my judgment upon the evidence of others, which leads me to believe that these waters come from the sands of the Eo-Lignitic[*] or Camden beds which underlie the great timbered region of Texas and eastern Arkansas. If these are the same sands from which Marshall and other cities of Texas secure artesian water, it should supply a means of great development for Atascosa and adjacent counties.

The wells of the coastal region are derived from the Washington and Fayette sands.

The same beds which underlie Houston and Galveston extend along the coast southwestward and supply artesian flows at Yorktown, Velasco, Gonzales, Cuero, and San Patricio, at shallow depths varying from 40 feet at Yorktown to 966 near Patricio. There is little doubt but that these wells can be obtained along the whole coastal region for 50 miles inland.

I have now discussed the great artesian conditions of the coastward incline of Texas, and can only add that in this whole region, with the exceptions noted, wells can be obtained at moderate depths.

The slight coastward slope of the whole region and the corresponding inclination of its underlying beds indicate a good supply from one or more of the underlying sandstones anywhere that a well will be drilled deep enough. While the flow may be small, even any amount will be a great boon to the region.

V.

WATER CONDITIONS OF THE CARBONIFEROUS AND OLDER PALEOZOIC REGION OF CENTRAL TEXAS.

Good wells (nonflowing) are abundant throughout most of this region, and several small artesian wells of poor quality and flow have been reported. Concerning this region Mr. Roessler has said:

> Between the ninety-ninth and one hundred and first meridians the borings have been failures throughout. In most cases, as at Cisco, Eastland, Baird, Colorado, and Big Springs, no flow was secured, leaving the few small shallow wells at Wayland, Stephens County, out of the calculation on account of their small flow. Where a flow has been secured, it was either mineral or impregnated with salt, coal gas, etc., as at Trickham, Coleman County; Gordon, Palo Pinto County; San Antonio, Eden, Concho County, and other places. The pressure necessary for artesian wells is present in all the wells mentioned.

The structure of the region is unfavorable for any large flow of water, and I do not advise further experiments. In Burnet County one or two small flows have been secured out of hundreds of borings made with the diamond drill by mineral prospectors.

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[*] For a full description of the lithology of these sands, see report of Arkansas State Geological Survey, Vol. 2, 1888.

VI.

WATER CONDITIONS IN THE RED BEDS REGION.

[Western Indian Territory, the Canadian and Pecos valleys of New Mexico, and the Abilene, Concho, and Wichita countries of Texas.]

This region is one of the most striking and important of the geographic features of the Southwest. Its name is derived from the fact that the surface of the whole country underlaid by it is of conspicuous red colors, glaring vermilion or deep-brown chocolate sometimes prevailing, varied only here and there by a bed of snow-white gypsum. To one accustomed to the green-clad landscape of the east or its somber-colored formations, the vast landscapes and brilliant colors of the Red Beds is striking, especially if seen in some bold cliff for scores of miles. A landscape in color that of red brick dust is the only familiar comparison.

These beds occupy a vast extent of country in Oklahoma, Texas, and New Mexico, aggregating 100,000 square miles, as seen upon the map, occupying all the nonmountainous region, except where covered by the Llano Estacado formation, from southern Kansas to the trans-Pecos Mountains, and westward around the southern termination of the Rockies, through New Mexico, Utah, and Oregon, to the Sierras. They have not been recorded far south of the Southern Pacific Road, nor do they anywhere appear in Mexico north of Catorce, the Cretaceous still covering that area. The valleys of the Canadian and the Pecos reveal their presence beneath the Llano Estacado, and the Grand Cañon of the Colorado shows them in Arizona and Utah. Occasionally they appear in the flanks of the Rocky Mountains. Their characteristic and most perfect exposures are in the country between the ninety-ninth and one hundredth meridians south of the Arkansas and north of the Conchos, embracing portions of Texas, Indian Territory, Oklahoma, No Man's Land, and nearly all of Oklahoma, where they occupy beautiful prairies, including those of the celebrated Wichita, Concho, and Abilene countries, which embrace fine agricultural lands of Texas and the Oklahoma country. They also include much of the Pecos Valley, especially east of Eddy, between the river and the plains, and from Roswell northward to near the crossings of the river and the Santa Fe Railway.

Along the eastern escarpment of the Llano Estacado and up the cañons of the Brazos, Colorado, and Red rivers that incise it, and up the valley of the Canadian, there are beautiful bluffs of these vermilion beds, with an occasional butte or mesa.

These beds constitute the foundation of the northern and eastern edge of the Llano Estacado north of the Colorado.

The principal area of the Red Beds is that of western Indian Territory and northwestern Texas, between the Llano Estacado on the west and the Coal Measures on the east. This stretches from the thirty-eighth to the thirty-second parallel, a distance of 350 miles north and south and from the ninety-eighth to the one hundredth degrees of longitude, or averages 150 miles in width, a total of 52,500 square miles—an unbroken prairie, except small areas occupied by the Witchita Mountains and a few remnant buttes of the Grand Prairie and Llano Estacado formations which have been preserved to remind us of the vast erosion the region has undergone.

The next area in size is in north central New Mexico, on either side of the Canadian and Pecos, after those streams have emerged from the mountains and adjacent plateaus. This valley is an enormous trough furrowed out of the Raton and Llano Estacado plateaus by erosion. Its northern boundary is the superb Corazon escarpment which runs eastward from Pecos, crossing to the Texas line. This escarpment, as shown upon the topographic maps of the United States Geological Survey, is over 1,200 feet in height above the Canadian River. It extends irregularly northeastward for 100 miles until overlapped by the plains surrounding a magnificent valley of the Red Beds, in the lowest portions of which the drainage of the Canadian and Pecos are at an altitude of 4,000 feet, or over 2,000 below its summit.

This valley plain is irregular in outline, as shown on maps, but of great area. In it the drainages of the Pecos and Canadian separate on their long and different journeys to the sea around the northwest escarpment of the Llando Estacado, which looms up in the distance like a mystic wall. Language can not describe the magnificence of the scenery; everywhere upon it is seen the grand and deep erosion by which the overlapping formations have been stripped from the horizontal Red Beds, and, as if to make the fact more impressive, nature has left standing in the valley numerous remnants of the plain in the shape of great circular buttes and mesas as El Corazon, the Gavilian Mesa Rico, Mesa Redondo, the big and little Huerfano, Mesa Tucumcarri, and others, every stratum of their red and white beds visible for miles and showing the lack of artesian conditions. These superb buttes of the Canadian valley are among the most interesting features of our country, and as they have been the subject of much controversy, I present a description of one of them by Capt. Jas. B. Simpson, U. S. A., written some forty years ago.[*]

> Soon after taking up the line of march a small, faint, cloud-like appearance of small but growing extent exhibited itself, bearing magnetically nearly west. A few miles further on this appearance gave away to a well-defined truncated one. Proceeding still further on, and in proportion as we progressed, a dome-like appearance gradually unfolded itself, till at length, when we had almost reached our present camp, an assemblage appeared which did not fail to strike many of us as being an excellent representation of the dome of the Capitol at Washington. This object, which we have been gazing at nearly all day with the greatest interest, we take to be a Cerro de Tucumcarri. Passing over a poor soil we reached Cerro de Tucumcarri. After a laborious ascent, of which some fifty feet were nearly vertical, we reached its summit. On every side was an unobstructed view. To the west and south lay a confused mass of irregular hills, with here and there a well-defined and conical one to characterise the scene. Far behind to the west lay a range of mountains or hills and more conspicuous than the rest of the high peak. To the south, some 8 miles distant, I could see with my reconnoitering glass the serrated tents of our command, reposing on a timbered affluent of the Canadian. To the southeast and east lay the famous 'Llano Estacado' of the Mexicans. To the northeast and north lay a limitless, unbroken, and undulating prairie, no signs of the Canadian being apparent. Pacing the top of the mound, I found it to be 230 yards, by 370 in area; and, by a measurement of the slope of the hill and roughly reducing it to an angle of 45 degrees, I made its height over 700 feet (900 feet above the Canadian). The circumference of its base to our surprise I found to be nearly 6 miles, it having taken a horse two hours less eight minutes to walk around it. (P. 14.)
>
> Following up Tucumcarri Creek, a fine view made up of sugar-loafed hills and tablean mounds, and opening vistas, presents itself to your front. The regular stratification of these hills, their pearly white and red color in horizontal zones, and the whole surface besprinkled as they are, with stunted cedar of a dark-green color, will not be failed to be noticed by the traveler as giving them a very beautiful and unique character. The formation of these hills, which are from 100 to 300 and 400 feet high, is at the base a red argillaceous rock, the Red Beds, easily frangible; next proceeding upward, a zone of sandstone rock (the Trinity Sands), very friable and of a greenish-white color; last and uppermost, a sandstone rock (the Dakota Sands), of a brownish hue and rather coarse character. Large fragments of these last-mentioned rocks lie scattered on the tops of the hills."

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[*] Thirty-first Congress, first session, House of Representatives, Ex. Doc. No. 44, Report of Exploration and survey of route from Fort Smith, Ark., to Santa Fe, N. Mex., made in 1849, by Lieut. James H. Simpson, Corp of Topographical Engineers; also a report on the same subject from Capt. R. B. Marcy, Fifth Infantry,

The writer has twice visited the Mesa Tucumcarri and found it a most interesting geological remnant of the former area of the Llano Estacado. The table or summit described by Capt. Simpson is covered with the typical Llano Estacado formation, identical in composition and formerly continuous with the sheet which covers the Llano proper, some 20 miles distant. Below this is a vertical escarpment of 50 feet or more of typical Dakota sandstone resting upon loose sands and clays, forming a slope identical in aspect and fossil remains with the Denison beds of the Washita Division, which have been eroded away from the 400 miles intervening between it and the main body of those beds at Denison, Tex. Beneath this is a large deposit of the typical Trinity sands country, of white pack sands, thin clay seams, and flagstones, while the base is composed of the typical vermilion sandy clays of the Red Beds.

This valley has several small creeks at intervals of 15 to 30 miles apart, such as the Concho, La Cinto, Truxillo, Plaza Largo, and one or two others, the water of which is all the escarpment drainage of the Llano and could be used for irrigation of about 1 acre in 1,000 of the beautiful land, as is now used at Dutch Henry's Ranch, the only Caucasian settlement between Las Vegas and Bell Ranche, 100 miles east, where a steam engine is used to irrigate about 20 acres. The scarcity of fuel, however, would not allow this mode of irrigation to be extensively used.

Around the edges of the escarpment of these valleys there are occasional springs many miles apart which usually have their origin at the contact of the Red Beds and the overlying sands of the Dakota or Llano Estacado, from which the water is derived, and which will be discussed in these chapters relating to those formations.

In the Red Beds proper there are few wells, the only one of note being that at the cattle ranch at the northeast base of Tucumcarri Mesa, which supplies an abundance of water, which is pumped for cattle; this leads us to infer that others could be obtained.

The Red Beds also extend down the valley of the Pecos from its divergence from the Canadian around the western border of the Llano Estacado. This prolongation continues to the Texas line and occupies nearly 5,000 square miles of area. From Eddy to 60 miles south of Pecos they are overlapped by later formations, but appear again in the vicinity of the Castle Mountains. There are other isolated patches in eastern and central Mexico of considerable area, of which details must be omitted.

The Red Beds are composed of finely comminuted material, mostly red clay and sand, usually thoroughly mixed together, accompanied sometimes by beds of coarse, loosely cemented, greenish and chocolate colored sandstone, which weathers into circular turban-shaped masses. Occasionally, as at Guthrie, Okla., and Tascosa, Tex., there is a species of conglomerate, the pebble always being composed of the sands and clays of its own beds. While, no doubt, a continuous and unbroken formation from the bottom to the top, there are other variations in structure which are here noted.

In their lower portion there are darker-colored chocolates, and copperas green tints occur frequently, and a greater amount of rounded sand of varying coarseness. The rocks of this division are well displayed in the southeastern half of Oklahoma, at Henrietta, Colorado City, Tascosa, and other points in Texas, and in the valley of the Canadian from the mouth of Cañon del Agua, New Mexico, to east of the Texas line. Occasional fragments of fossil wood and remains of plants, reptiles, mollusks, etc., have been reported from localities which I believe to be in these beds, and ascribed to the Permian age. This lower division of the Red Beds is also characterized by excessive cross-bedding and lack of persistent planes of stratification.

The beds become finer, more argillaceous and gypsyferous in their middle division, as can be seen in the fine brick-dust clays of the Pecos and Canadian valleys (notably the base of Sierra Tucumcarri), in the lower third of Cañon Blanco, in the eastern edge of the Llano Estacado, and in the vicinity of Sweetwater County, and Vernon, Wildbarger County, Tex.

The escarpment of the Llano Estacado in Texas and New Mexico, affords superb displays of these brilliantly colored strata, often alternating with bands of pure white, saccharoidal gypsum,

The beds of gypsum occur over a great area and its quantity is inexhaustible (Fig. 10). The strata are from a few inches to 20 feet in thickness, usually of a pure white color, presenting a strong contrast with the vermilion layers with which it is embedded. It is present in Kansas, New Mexico, Oklahoma, and Texas in great abundance, and is the most important economic feature in the whole Red Beds region, in that its presence is the basis of the fertility of the Red Beds and it is readily soluble in water and usually accompanied by it. The water is often so strongly impregnated with it that the term "gyp water" is a common expression throughout the region. Although until recently unappreciated it is rapidly becoming an important economic feature, and is being manufactured into plaster Paris, an adamant wall plaster, in great quantities.

Gypsum also occurs in bright crystals resembling mica, for which it is commonly mistaken. In eastern Mexico the gypsum is often soft like pulverent flour and is known as jeso (yaso). This jeso is often mistaken for the injurious "alkali," when in fact it is a most important element in the fertility of a soil. Miles and miles of jeso can be seen in the Pecos Valley where it is blown about by the winds.

In the Tularosa Valley, at the head of the Franklin-Hueco basin, the gypsum is granular and is known as the white sands. These sands extend for many square miles and resemble siliceous sand. They contain a great amount of water and it is only necessary to dig a few feet to obtain wells throughout their extent.

The term Red Beds is geologically used to denote the vast series of red-colored deposits below the well defined Trinity sands and above the undoubted Permo-Carboniferous. Their age (which is utterly immaterial to the question of artesian water) certainly ranges from Permian at their base, as shown by the investigations of Cope, Boll, and White, in Wichita counties of Texas, to Triassic, as shown by Newberry and Marcou, in Texas and New Mexico, and probably Jurassic—continuing to the base of the Comanche series, as seen in the Cheyenne sandstones of Kansas and at the base of Tucumcarri, N. Mex.

Whatever their age, they have the same unmistakable characteristics of color and unconsolidation and are probably a single unbroken formation, representing the sediments of an ancient inland sea, which extended from the ninety eighth meridian westward to the Sierras and from the northern United States nearly to Mexico.

The beds of the flowing rivers arising in the escarpment of plains are in the Red Beds formation, to-wit: The Cimarron from near the one hundredth meridian to east of Guthrie. The Canadian from Camp Supply to the Santa Fe Railroad. The Red River from its head in Cañon Blanco to Montague County, Texas. The Pease and Wichita from their head to mouth. The Brazos, from its head to Young County.

olorado and tributaries from source to near Ballinger, Runnels
ty ; the Pecos from the mountains to Roswell, N. Mex., and from
v Pecos city to beyond Castle Buttes.
though these rivers flow through and drain the Red Beds in time
oods, not one of them has its permanent or spring water supply
them, all receiving their water either from the underground drain-
of the Llano Estacado or the mountains, but in flood times these
ams are all characterized by their phenomenal vermilion-colored
hets, ordinarily known as "red rises," which flow down in great
me after the sudden and excessive rainfalls, which come in June,
, and August, in the Red Beds region.
the stream drains the Red Beds only, as the Pease and Wichita,
of its rises are of this vermilion hue, owing to the excessive Red
sediment which they contain. If it flows through a diversity of
logic formations and finds its way into the humid region, like the
zos, Red, and Colorado, then its flood will vary in color with the
valent color of the rock of the region upon which the rain has
en. Thus, at Austin, on the Colorado, where these floods come often
imes of local drought, the extent of the region affected by rainfall
always be told by the white and red rises—the former coming from
limestone country, and the latter from the Concho Colorado red
ls country. If there has been rain in both, the white flood precedes
red.
he lower beds from their coarser structure and excessive cross-
ding present few conditions for the storage of water, and as a rule
ngs are few and rare. In fact, I do not know a single spring com-
from these beds of sufficient size to be valuable for extensive irriga
, though often they are large enough to supply domestic purposes
urface wells are obtained of large capacity, but as a rule are rather
p and scant, except along the less arid eastern border of this out-
.
have as yet failed to observe a single flowing artesian well in the
Bed area, and doubt if one can be obtained, although one has been
orted near Seymour, Tex., the water being of small flow and highly
regnated. The pervious basal layers are too irregular and unreli-
e to convey water to a great distance, and the upper or Triassic
ision too impervious. In Texas and New Mexico the conditions of
and induration are inevitably against the topographic slope, and
ce unfavorable to artesian conditions, as seen in the sections and
res.
he springs in the valley of the Canadian at Tascosa, which rise ap-
ently from the Red Beds, I am inclined to believe have their origin
the neighboring Llano Estacado beds, which cap the adjacent mesa
e.
n Indian Territory and Oklahoma the inclination of the strata is dif-
ent and of a nature to warrant the conclusion that experiment in
se regions is justifiable.
The largest and most favorable non-flowing well observed in the Red
ds was that of Col. E. C. Eddy, at his headquarter's ranch, 25 miles
st of Eddy on the Pecos, New Mexico. Here in the center of a large
sin, which is apparently a lake in time of rainfall, a well has been
g to a short depth, and 3,000 cattle are daily watered by aid of a
mp, which is of the chain-bucket type, and operated by horse power.
umerous other wells in the area of the Red Beds lying in the Pecos,
tween the escarpment of the Llano Estacado and the Guadalupe dis
ict, have led the writer to infer that non-flowing water will be found
uite abundantly in all of these lower areas.

Experimental wells have been bored in the Red Beds at Colorado City and at Abilene, the latter having descended 1,000 feet at last reports, with no success. At the former place salt was struck at a depth of 760 feet. All deep wells in the Red Beds strike salt.

VII.

WATER CONDITIONS OF THE LLANO ESTACADO.

For that portion of the great plain proper lying south of the Canadian River and east of the Pecos the term Llano Estacado was appropriately applied by the early Spanish explorers. In surface features the northwestern half of this plain is similar to the plains of Colorado, Kansas, and northward, but differs from them in that, instead of extending to the Rocky Mountains on the west or imperceptibly grading into the level of the eastern areas, it is surrounded on every side, except a few miles at its southeast corner, by a more or less precipitate escarpment of erosion resembling palisades, which completely insulate it from connection with other regions, except the Edwards Plateau, which is its southeastern continuation and genetically a portion of it.

The vast surface of the Llano Estacado, at least 50,000 square miles, is practically smooth with the exception of an occasional depression, so much so as to resemble the level of the ocean at dead calm and unbroken by trees or bushes or deep drained channels, and carpeted with a rich growth of gramma grass.

Within the past few years the new railroads of Texas and New Mexico have made accessible to the geologist this largest of all Texas plains, and perhaps areally the greatest continuous and least studied plateau of our country. (See Pl. II.) Geographically the "Staked Plains"[*] of Texas and New Mexico include the quadrangular region south of the Canadian, east of the Pecos, and west of the one hundred and first meridian. The small amount of surface water, which is not imbibed by the soil, is found in a few widely-distributed ponds. Its eastern and northern edges are incised by deep and vertical cañons of streams which are cutting by backward or headwater erosion. Two streams flow around the plains. These are the Canadian and Pecos, both of which have cut nearly 1,000 feet below its level and neither receives any of its surface drainage. The rainfall, principally from June to September, is estimated from 20 to 25 inches.

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[*] The name Staked Plains should be dropped from geographic nomenclature as the descriptive name for the great mesa to which it is applied. One popular apology for the use of this term is that early travelers set up stakes to mark their roads over these—then considered—waterless wastes. Another is that the term alludes to the staff-like stems of the yucca plant, which resemble stakes projecting above the ground. Neither of these hypotheses, however, will stand the test of application, for the traveler could not possibly have secured on the absolutely treeless plains timber wherewith to make his stakes, and the yucca does not grow upon them. Upon the other hand, a glance at the Spanish dictionary will show that it will be impossible to translate the word "estacado" to mean a stake, but upon the contrary it means exactly the opposite, a palisade or wall, which is a most appropriate descriptive term for the Llano Estacado, inasmuch as it alludes to the sharp declivity or face of the escarpment which in many places marks the edge of these plains. In view of these facts it is as erroneous to use the term Staked Plains for the Llano Estacado as to write the name L'Eau Frais, "Low Freight," as is done upon maps of Arkansas.

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The surface of the plain is everywhere composed of the transported sedimentary soil described as the Staked Plain formation, which is from 10 to 30 feet deep. From its structure and composition, it is evident that it is either a deposit laid down in late miocene time. The formation and its resultant soil differs from all others in Texas, and notwithstanding the deficient rainfall the plains are covered with short, nutritious gramma grass. Although apparently level, this great plain inclines rapidly seaward, at the rate of 20 feet per mile, its western margin having an altitude of 5,000 feet, and its eastern only 2,500.

Owing to the excessive porosity of the soil, the surface is void of deep-cut drainage channels, such as creeks, rivers, and cañons, although the Pecos and Canadian have cut completely across and through it, and many stream like the Red. Brazos, and the Colorado, by head-water erosion, are rapidly incasing its eastern border, and will eventually destroy it. (See Pl. II).

The escarpment of the Llano Estacado is one of the most remarkable topographic features of our continent, presenting from almost every view the appearance of a precipitous wall, often visible from 50 miles distant, escalloped or serrated by rain washes, like the bluffs of the Mauvaise Terre or bad lands of the Northwest. The western portion of this escarpment, extending from the Canadian, in New Mexico, to the Rio Grande, Texas, in a southeasterly direction subparallel to the Pecos River, is apparently unbroken by an interceding drainage. It extends east of Sumner, Roswell, and Eddy, and is the eastern limit of the drainage basin of the Pecos River, which stream, now 900 feet below its general level, has no doubt destroyed the former western extent of the Llano Estacado and its contact with the mountains, from which it is now everywhere from 50 to 100 miles distant.

The northern escarpment forms the southern bluff of the valley of the Canadian River. This escarpment is the most precipitous of all and is exactly similar in general features to the opposing bluffs of the Corazon, mentioned in the chapter on the Red Beds.

The southern continuation of the Llano Estacado is the Edwards Plateau (previously described), which is a part of the plain and a result of the same geologic causes, although different in underlying structure.

As was remarked by Capt. Mayne Reid in one of his early romances of the prairies, the Llano Estacado is simply a vast quadrangular mesa, which is elevated above all surrounding regions. Its slope and precipitate border can be likened to a book resting upon a flat table.

The geological structure of the Llano Estacado is as simple and uniform as its topography, consisting of a surface or capsheet of unconsolidated porous sediments, composed mostly of waterworn sands, pebble gravel, and silt, occurring in horizontal layers and averaging 200 feet in thickness throughout its extent, as ascertained by numerous well borings and measurements of the escarpments. The greatest thickness of the formation is towards the eastern margin of the plain, gradually thinning westward.

The peculiar heterogeneous character of the unconsolidated formation has been well described by Prof. Robert Hay, as grits, mortar beds, and marls. Certain layers are composed of hard siliceous gravel which are recognizable as the débris of well-known Rocky Mountain formations. Others consist of coarse waterworn quartz sand, loosely cemented by a lime matrix, so that it is literally coarse mortar beds. The marl is usually pinkish or light chocolate brown, and when watered forms a rich agricultural soil. Another typical aspect is known to the

Mexicans as the "tierra blanca," or white earth. This is found as strata of a white calcareous chalky earth possessing strong hydraulic or setting powers, and usually the protecting or cap layers of the escarpment. The tierra blanca is well shown, north of Tascosa, in the bluffs of the Canadian; in the bluffs of the Palo Douro Cañon; in the railway cuts of the Texas Pacific, west of Sweetwater, Nolan County; and in the western escarpment along the Pecos Valley.

This porous unconsolidated structure of the Llano, as will be shown later, has important bearing upon its water conditions.

These sediments may have been the deposit of a vast lake which occupied the region of the great plains in late Tertiary time, but I am inclined to believe them the marginal deposits of the Gulf of Mexico, although different in physical character from other formations, discussed in this report, of marine origin and different conditions of oceanic sedimentation.

This formation has been described minutely by Newberry, Hay, and Shumard. The descriptions by Prof. Newberry of the plains of western Kansas and No-Man's Land, although he was not aware of the similar structure of the Llano, are so applicable to the latter region, which is the same formation, that it is here given in his language. He says: *

> The detail of structure of the Tertiary basin of the Arkansas will be, perhaps, most readily understood by a few extracts from my notes, made at various points along our journey, where the Tertiary strata are exposed. "After leaving Pawnee Fork the road passes over the level bottom lands for several miles, * * * when it rises out and crosses the table-land, which separates the valleys of Pawnee Fork and the Upper Arkansas. This table land is underlain by a white tufaceous limestone, exposed in the bed of the Coon Creek, and still better at the point where the dry road comes down again to the Arkansas. It is also thrown out in many different places from the burrows of the prairie dogs. In lithological characters this rock is precisely like a portion of the strata of the bad lands of Nebraska, contains no fossils, but a few pebbles of crystalline rock. At the Caches, 16 miles below the crossing of the Arkansas, the same stratum is seen overlain by some 30 feet of coarse, soft, light-brown conglomerate, much cross stratified. The cement is coarse siliceous sand; the pebbles, from the size of an egg downward, of granite traps, quartz, trachyte, jasper, quartzite, charb, etc., with a few of Carboniferous limestone.
>
> "At the crossing of the Arkansas the following section is exposed: 1. Spongy tufaceous limestone like that on dry road. 2. Coarse soft conglomerate, same as at Caches, 35 feet. 3. Tufaceous limestone, like No. 1, to base. The sand hills which border the Arkansas on the south side seem to have been derived from the decompositions of the Tertiary conglomerate.
>
> "The same stratum forms the banks of the Cimarron, and has apparently given character to its sandy and sterile valley. The 'Jornado,' the divide between the Arkansas and the Cimarron, is another portion of the high prairie, precisely alike in typical and geological structure that crossed by the 'dry road.'"
>
> At Eighteen Mile Ridge, on the Cimarron, the coarse conglomerate and chalky tufas are exposed, as at many points below. The conglomerate is composed of a coarse sandy cement with pebbles from the size of shot to 8 inches in diameter. The larger ones are compact, fine grained, reddish yellow sandstone, doubtless of lower Cretaceous age, and such as comes to the surface further westward. Others are composed of granite, amygdaloid, clay slate quartz, jasper, etc. The greater size of the pebbles in the conglomerate indicates that, in going westward, we are approaching the source from which they were derived. The conglomerate would seem to be a drift from the Rocky Mountains, where and where only, as far as I am aware, such materials occur in place.

Along the cañons of the head of Red River, at the northeast corner of the Llano, the deep incisions have been made, revealing escarpments excelled in beauty by only those of the Grand Cañon of the Colorado, which they much resemble in color and stratigraphy. Several

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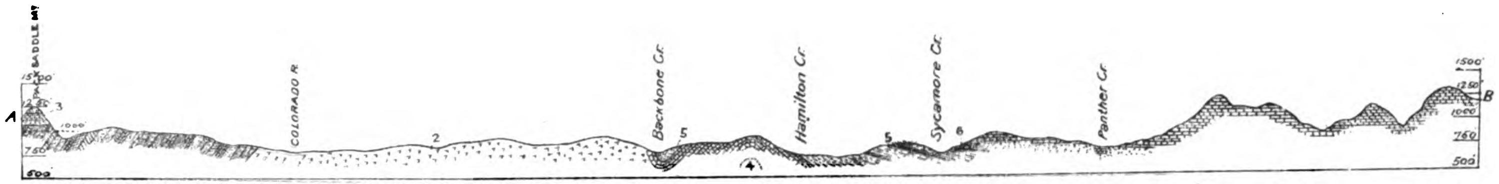
* Report of the exploring expedition from Santa Fe, New Mexico, to the junction of the Grand and Green rivers of the Colorado of the West, in 1859, under command of Capt. J. N. Macomb, Corps of Topographical Engineers, with geological report by Prof. J. S. Newberry, 1878, geologist of expedition, pp. 24 and 25.



SECTION From MARBLE FALLS
TO TRAVIS PEAK SHOWING BASAL WATER BEDS OF COMANCHE SERIES IN CONTACT
WITH THE IMPERVIOUS PALEOZOIC FLOOR AT SYCAMORE CREEK

8 Ex 41 ...... 52 1

sections have been published of these and beautiful illustrations given in Capt. Marcy's Report on the Exploration of Red River of Louisiana, and by Dr. G. G. Shumard, and later by Rev. W. F. Cummins.

In general these sections show the following succession:

			Feet.
1.	The Llano Estacado beds prevalent color: Light chalky, showing occasional faint tints of yellow and pink.	Loose surface soil, sandy red	8 to 20
		White calcareous "pan" or tierra blanco	2
		Sands usually slightly compact	2 to 10
		White pan, often siliceous and honeycombed	2 to 5
		Impure calcareous sands and clay	30 to 40
		Tierra blanco	2 to 10
		Loose rounded sands, mortar beds	20
		Greenish white clays	30
2.	Upper Red Beds. Red vermilion clays forming lower cliffs of cañon, and showing an exposure of		150 to 200

This surface formation of the Llano extends southward of the Texas Pacific onto the Edwards Plateau an indefinite distance. It reaches the Rio Grande, in Val Verde County, north of Del Rio; and I am inclined to believe that it once covered the whole of the Edwards Plateau and has since been eroded. There are features in the coastward regions of Texas, in the Rio Grande embayment, closely related, which I have described as the Washington prairies.

The floor of the Llano Estacado, or that portion underlying the above-described cap formation and outcropping as the basal portions of its escarpment, is of entirely different material, and since it is of great importance to the water question it must be described.

Its relation to the Llano formation can be conceived, however, by considering the present diversity of formations outcropping, *i. e.*, constituting the earth's surface, sands, clays, granites, etc., and imagining a great subsidence which would reduce these to a common base level and spread over the diverse rocks a sheet of sediment like that of the Llano. It was upon such a surface as the present that the cap sheet of Llano sediments was laid down, which, although concealed as by a veil, let us examine for a moment in order to understand its relation to water. (See profiles on Pl. II.)

Toward the north this floor was eroded down to the Trinity sands previous to the deposition of the Llano beds, and even these are worn down to the Red Beds for the greater portion of the foundation occurring under the western and southern margins.

These Trinity sands, partially constituting the floor of the plains, can be seen in the escarpment east of Eddy, New Mexico, at Headquarters ranch; the limestone and clay beds of the Comanche series are absent. Most of the sand hills of Texas and New Mexico, which cover hundreds of square miles at the foot of the western escarpment of the plains, I consider to be the remnant of this formation.

Along the western escarpment of the plains and in many of the buttes and mesas of the Canadian valleys the same Trinity sands outcrop again. There is little evidence of their presence along the entire northeast quarter, as shown in the cañons of the Red and Canadian rivers, the plains formation resting directly upon the Red Beds. Wherever this sand occurs immediately beneath the plains formation without the intervention of impervious beds, water will be found in great quantities. At the northwest corner, however, between the Trinity beds and the Staked Plains beds is a great sheet of Dakota sandstone and Denison beds, as seen in Tucumcarri mesa, a remnant of the Llano Estacado.

South of the thirty-second parallel this floor is composed of the rocks of the Comanche series from the Trinity sands to the Caprina limestone, the latter formation constituting by far the greatest area and extending over thousands of square miles in the counties of Midland, Ector, Tom Green, Coke, Glasscock, Crane, Upton, Irion, Menard, Crickett, Sutton, Kimble, Edwards, Val Verde, Kinney, Pecos.

The erosion of the limestones of the Comanche series from the whole region approximately north of the Texas Pacific Railway and west of one hundredth meridian preceding and closing the Great Llano epoch is beyond conception, and we must leave to the purely scientific treatise the discussion of the facts.

The entirely different characteristics of the Llano formation, such as color, composition, and vegetation, render it readily distinguishable from the underlying floor, as seen in the numerous contacts all around the escarpments and in the deeply incised cañons of Red and Colorado rivers along the eastern margin.

As vast as the area of this great mesa now is, it is only a remnant of its former extent, so great and rapid is the process of atmospheric land stripping in the West. There can be no doubt that it continued northward across the valley of the Canadian and other stream as a part of the Tertiary plains of Kansas.

To the eastward its borders extend to the ninety-ninth meridian, having since receded, as it is now receding, by headwater erosion of the streams to its present outline. To the south these plains extend into Mexico and Texas. To the west there is no doubt that these plains extended to Raton Mesa and around the southern end of the Rocky Mountains, south of Santa Fe, on to New Mexico and Arizona. Fragments of it still remain and the Pecos Valley escarpment is traveling east at a wonderful rate.

Neither can there be any doubt but that the Llano Estacado formations covered the great Edwards Plateau, stretching southeastward nearly to San Antonio and Del Rio, now a barren limestone floor, and much of it has since been eroded.

The water of the Llano Estacado.—This vast mesa, with a few exceptions, is singularly void of surface water. It is true that after seasons of rainfall there are occasional ponds or lakes of water in the depressions, but some of these have been known to evaporate during the continuance of a south wind for a day or two. Running Water, in Dickens County, is the only stream on the Llano Estacado, and this really belongs to the marginal rivers of its eastern edge. It has been described by Mr. Roessler as "a bright sparkling stream that suddenly breaks out of the ground, ripples over pebbly bottoms for a distance of 10 miles, and then myteriously disappears like many other streams west of the Pecos River, notably Leon Wells, Comanche Springs, Escondida, Limpia, and Toysh Creek, or the underground river near Castle Mountain in Crane County."

Why this absence of running water over 50,000 square miles of area which posesses a fair rainfall and presents every favorable topographic condition for them? The only answer is that the capping strata of the Llano Estacado are as porous as a sponge, and that every drop of rainfall is either evaporated or taken in and percolates downward until it reaches an impervious stratum. That such is the fact has been borne out by a thousand experiments in the Llano and by the study of its scarp and cañons.

Although considered until the last fifteen years an utterly waterless plain—the largest in America—it is a remarkable fact that over 1,000 wells have been dug into this sheet of strata and water obtained—not of flowing water, it is true, but water which is easily pumped by aid of windmills and which make possible the pasturage of thousands of cattle. These wells have been obtained throughout the whole extent of the vast mesa, and with such success that failure is seldom experienced. Mr. Roessler's statistics show the wonderful distribution of these wells in the counties of the plains in Texas and eastern New Mexico, and there are hundreds more. A study of the drill holes shows that this supply of water comes from the Llano formation in the northern part of the plains, and that it is hopeless to bore into the impervious Red Beds that underlie them, which serve a most valuable function in preventing the farther downward percolation of the water. In the beautiful Blanco and Palo Douro cañons, and all around the northeastern escarpments, the spring line can be seen, where this water of the plain is oozing out at the contact of the Llano formation and the Red Beds. This water is an underground product of the Llano, and from its seepage the supply of the Red, the Colorado, Pease, Wishita, and Brazos is obtained.

This water is stored in the mortar beds and grits of the Llano Estacado formation and is the most remarkable sheet of underground water in our land. Not only is it seen in the heads of the Texas stream, but it follows the escarpment of this mesa up the Canadian 200 miles and around its northwestern point in New Mexico; and thence down the Pecos escarpment again to the Texas line; and you will see many streams and springs flowing out at the line of contact between the Llano formation and the underlying Red Beds. Of such a nature are the Truxillo, the Tucumcarri, the Pajarito, the Portillo, the Alamequada creeks and the springs of the Conejo, Mescalero, Gintrez, and others in eastern New Mexico.

In the southern and southeastern portion of the Llano the well water and springs are obtained from the Trinity sands which at Marienfield and Big Springs are intercolated between the Llano formation and the Red Beds. (See sec. 3, Pl. II.) To reach this sand a slight remnant of the Comanche Peak and Gryphæa beds are first penetrated.

Can artesian water be obtained on the Llano? That the underground sheet water of the Llano beds can be struck throughout the extent of the mesa has been everywhere demonstrated. But it is also apparent that since this water occurs in the surface formation—the Llano beds—there can be no hydrostatic pressure to force a surface flow. But there are other strata underlying portions of the Llano, beneath the Llano water sheet, and to these we have cause to look with much hope that they may present favorable artesian conditions. To understand them, however, it is well to carry in mind the discussion of the underlying floor of the plain and to possess an idea of the sequence and water conditions of the Neozoic strata upon which the Llano beds are deposited. These foundation beds are as follows:

3. Colorado Beds	7. Upper sands	Pervious, good.
	6. Colorado clays and lime	Impervious, bad.
	5. Dakota sands	Pervious, good.
2. Comanche Beds	4. Denison sands	Pervious, good.
	3. Chalk limestone	Impervious, bad.
	2. Trinity sands	Pervious, good.
1. The Red Beds	1. Sands and clays.	

Now, wherever the Llano Estacado formations rests on the impervious Red Beds or Colorado clays, the downward percolation of water will be stopped by these formations and they will form a bottom against which the water will rest and which will confine the water of the lower beds, but if Nos. 1, 2, 3, 4, 5, and 7 should underlie the Llano formation, then water would be percolated downward through them until some other impervious layer is reached.

As I have shown, it is only the northeastern half of the plain in which the Llano beds rest directly upon the nonwater-bearing Red Beds, and that the northwestern and southern portions are based upon the various beds of the Trinity, Comanche, and Dakota, which, outcropping along the western border, incline eastward beneath the plain, and may serve as artesian water-bearing beds. This relation of the floor to the plain is shown in the accompanying figures.

Furthermore, it has been observed that the water in the Llano formation does not rise under pressure in the well tube, but according to Roessler "nearly all the wells dug or bored through the Comanche limestone into the Trinity sands around the southern edge show a tendency to rise above the point where water was first reached. In some localities a rise of 20 to 30 feet was observed, showing that the supply is under considerable pressure."

Without committing myself to prophecy, it is my opinion that when the portion of the Llano along the Texas-New Mexican line is thoroughly prospected, somewhere in that region will be found an abundant artesian supply from the underlying Dakota and Trinity sands which outcrop so abundantly at a higher altitude in the northwest escarpment.

VIII.

WATER CONDITIONS OF THE TRANS-PECOS, OR BASIN REGIONS.

The portion of Texas and New Mexico west of the Pecos is a part of the vast region of North America which is known in Mexico as the High Plateau or Table Land, and in the United States between the Rocky Mountains and the Sierras as the Great Basin regions. It is characterized by the occurrence of disconnected mountain blocks, usually trending northward, separated by wide flats or plains, most of which in comparatively recent geologic time were occupied by vast inland lakes, several of which still exist, as the Great Salt Lake of Utah.

The mountains and basin plains of this region are popularly confused with the great Rocky Mountain system and the plains of the Llano Estacado and Raton Plateau types. This confusion is a serious error, however, for the great Rocky Mountain mass abruptly terminates south of Santa Fe, and is succeeded by the isolated and disconnected masses described in our chapter on the water conditions of the mountains, while the basin plains, instead of consisting of the coastward inclined stratification of the Llano Estacado, are fresh-water sediments deposited in the intramontane valleys.

This basin region was well defined by Major W. H. Emory, U. S. A., in his report upon the United States Mexican boundary in 1856, as follows:

> Between the two great chains, which I have attempted to describe, occupying the western portion of the continent, there are other chains of mountains, so numerous that it is impossible to describe them by words; some are continuous, some are detached ridges, others isolated peaks, rising from the plateau almost with the uniformity and symmetrical proportions of artificial structures. Between them are found basins which have no outlets to the ocean, but are the receptacles of the drainage of

surrounding watersheds. Of these, the most extensive is the Great Salt Lake in h Territory, and the most remarkable for its historical associations and present ortance is the present valley of the City of Mexico.

hese successions of basins form a prominent feature in the geography of North erica, extending two-thirds its length and quite one-third its breadth. They beg to what has been appropriately designated as the Basin system of North Amera.

Those found near the boundary are Santa Maria, Guzman, and Jaqui—all to the uth of the boundary and within the limits of Mexico. The first is fed by the waters f the river Santa Maria, which runs in a northern direction, and Guzman by the iver bearing the several names of Casas Grandes, San Miguel, and Janos, the genral course of which is also from the south to the north; and the waters of Lake uzman and Lake Santa Maria are said to unite in seasons of unusual freshets.

The waters of the Rio Mimbres, near the same meridian as Lake Guzman, which ake their rise near the Santa Rita del Cobre, run towards that lake, but they disapear in the plain to the north of the boundary before reaching it.

The waters of these lakes, or inland seas, are brackish at all times, but in seasons of drought, which last two-thirds of the year, they become salt and wholly unpaltable. Their shores are covered with lacustrine deposits, and are usually unsuited o cultivation.

Among the most conspicuous of the basins are the lakes Lahontan and Bonneville, in Utah and Nevada, Death's Valley in Arizona, the Mono basins of eastern California, the Organ-Hueco Valley, and the Jornado del Muerto in New Mexico; the valley of the Salt Lakes, the Eagle Flats, and the Toyah-Pecos basin in Texas, and the basin of Presidio del Norte, the plains of Chihuahua, the Bolson de Mapimi; the plains of Lago Aqua Verde, Baroteran, Barreal del Junco, Valle Hundido, Valle Labago Cayotte, and numerous others of Mexico.

It should be borne in mind that these basin plains cover extensive areas, and occupy much of the region, the mountains being almost secondary to them in extent and areal importance.

The basin plains are vast areas of apparently level lands lying between the mountains, consisting of loose unconsolidated sediment derived from the mountains, sands, clays, pebbles, and bowlders, sometimes cemented by white chalky efflorescent earths, which are apparently chemical precipitates. The surfaces instead of being level are really slightly depressed toward the center. The soil and vegetal products are peculiar. The former is often covered with alkaline incrustations, but is usually of exceedingly great fertility when irrigated. It supports a flora of stunted shrubs and grasses, such as mesquite, greasewood, artemesia, and cactus, entirely different from that of the adjacent foothills and mountains. Along the margins of these plains are great deposits of bowlders brought down from the mountains by the freshets, and covered with the peculiar yucca, sotol, istle, and other fibrous plants.

The basin valleys are usually void of surface streams, and the few water courses in the region are either slovenly flows that have no outlet, but disappear by imbibition and evaporation in their lower courses, or, like the Rio Grande and Colorado of the West, derive their waters from the mountains and merely flow through the basin region but do not originate in it.

Were it not for the mountains there would be no streams upon the basin plains, for all the water is derived from the precipitation upon the former, and is quickly drank in by the porous soil of the latter, thus constituting that class of streams known as "lost rivers."

The Rio Grande is by origin a Rocky Mountain stream, which originally emptied into one of the now vanished lakes, and after leaving the mountains and plateaus south of Albuquerque flows in the beds of these ancient basins, for nearly 300 miles, to the Quitman Mountain group of Texas, through which, in late geologic time, it has cut an outlet to the Gulf. The "passes" of the Rio Grande at Selden and El Paso are cut through the barriers between the former chains of lakes, now represented by the Jornado del Muerto plain, the Mesilla Valley, and the Organ-Hueco Valley respectively.

The Organ-Hueco Basin.—One of the most extensive and characteristic of these great inner mountain basins of the Tertiary sediment is that lying between the Organ-Franklin and Hueco-Sacramento ranges, in extreme western Texas and southern New Mexico.

This is a vast expanse of apparently "dead level" plain extending from the Rio Grande between El Paso and Fort Hancock, northward some 150 miles. It is 90 miles in width at its southern end, narrowing to less than 40 at its northern. The Rio Grande cuts through its southern end, exposing a grand section of the structure from El Paso on its western side to Fabyan Station on the eastern. This stream has grooved a channel from 200 feet in depth east of El Paso to 500 feet near Fort Hancock. The basin, although apparently level, slopes southward, according to the White Oaks Railroad profile, from 4,500 at its northern end to 3,500 feet at its southern end.

On all sides this flat or basin (locally called "mesa" at El Paso) is surrounded by high mountain blocks, including the Juarez and Mexican mountains on the south, the Franklin Organ and San Andreas blocks on the west, and the Sierra Blanca, Hueco, and Sacramento ranges on the east; all composed of hard impervious metamorphosed limestones, quartzites, granites, and lavas.

The basin proper is unmarked by a single drainage arroyo or channel except the Rio Grande and its laterals. The soil is a pink-gray sandy loam resembling that of the Llano Estacado, and is the residuum of the substructure of stratified, alternating, or unconsolidated sands (grits), clays, and water-worn gravel, often cemented by the white chalky-looking material known in the region as tierra blanca, or white earth.

This substructure of this basin formation is beautifully shown in the river escarpments or mesa east of El Paso, where the typical tierra blanca can be seen capping the scarp, and in the bluffs along the railroad between Etholen and Fort Hancock, where the soft disintegrating escarpment has every aspect of the typical bad land formations of Dakota.

The beds, like those of the Llano Estacado, are chiefly marked by their excessive lack of unconsolidation, the sands, clays, and gravel being almost as loose as when first deposited. White chalky lime strata resembling the Cretaceous beds are numerous, but upon examination they are always found to be conglomerates composed of débris of the jeso and chalk beds, red beds, and cretaceous, mixed with the mountain rock débris.

These beds are clearly laid down in the mountain trough or valley by lake sedimentation, and stream deltas are of newer and later age and never enter into the mountain structure, but are deposited unconformably, like a matrix, upon and around them, having a floor of impervious mountain rock (see plate 1, fig. 6). The thickness of the sediments would be difficult to estimate, but it varies from zero at the mountain edge to at least 1,500 feet in thickness in its southern center.

The northern end of this valley or basin presents several peculiar phenomena; the principal of which are the celebrated white sands. These are composed of rounded grains of gypsum instead of silica, and throughout their extent water is easily secured by digging a few feet.

The extreme northern end of the valley has been covered by a great flow of lava (or malpais) which it is alleged flowed down the valley some 30 miles from the craters of township 10, range 10, first standard parallel. This flat of valley has not upon its surface a single running stream or even drainage basin, and its surface is the most complete picture of aridity imaginable; yet, beneath it lies an illustration of one of the most important water principles in the west.

Franklin basin is surrounded by many terrace benches. These are of two kinds: Remnants of ancient shore lines and delta deposits of débris brought down by floods from the mountains. The terraces are especially well shown in the pass of the Rio Grande at El Paso, where on the western side, seven or eight tiers of them above the river levels can be traced. From the mountains which surround it on all sides considerable water is conducted to the margin of this basin plain, but it sinks almost immediately into its porous soils, percolating downward until resisted by the floor of impervious mountain rock which underlies it. At the northern end many of these mountain streams are perennial, and are good illustrations of the lost rivers of the west. The Rio Tularosa and the Tres Rios flow great volumes of water during the winter and autumnal seasons (precipitation upon these mountains being far greater, perhaps three-fold, than upon the plains), the latter being estimated at 8 annual inches. Immediately upon leaving the impervious mountain rock and upon reaching these plains these streams completely disappear, a phenomenon which can not but impress the observer with astonishment. They do not evaporate, as has been alleged, nor do they sink into caverns, as most people think, but they are imbibed, literally drunk up by the soft sponge-like formation of the plain, and are stored below the line of saturation. The shedding of its rain waters by the impervious mountain rock and its imbibition by the spongy plains rock is the key to the whole water question in the arid region.

The occurrence of the great amount of underground water in the Franklin-Hueco basin formation, at 200 feet beneath the surface, has suggested to many minds the possibility that beneath this there are other porous strata containing water, which sufficient hydrostatic pressure would force to the surface in the lower (Rio Grande) end of the valley. The structure of the ancient lake sediments is composed of alternate pervious and impervious layers of sand and clay beds, and these must have been more or less nested, one within another, in conformation with the topography of the ancient lake bottom, as shown in Pl. I, Fig. 6, affording good containing conditions for artesian water.

The great elevation of the northern end of the valley (where most of the water is received) above the lower is also favorable for artesian conditions, and finally, the fact that nearly all the artesian water in the arid region has been secured under identically similar conditions for similar basins, proves that the conditions for artesian water are at least worthy of thorough experimentation.

Wherever upon this apparently sterile plain an experiment has been made, abundant water has been secured at depths below 232 feet, and windmills pump it for irrigation. The record of these wells demonstrates the storage of much water below the line of evaporation in the deeper strata of the old lake sediments of the mesa.

The following record has been kindly furnished me by B. D. Russell, of El Paso:

Log of wells on Lanoria mesa.

	No. 2.[a]	No. 3.[b]	No. 4.[c]	No. 5.[d]	No. 6.[e]	No. 7.[f]
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Clay	25	10	8	9	12	10
Sand	32	30	[g]45	20	15	28
Clay	10	15	10	18	60	15
Sand	28	40	20	30	25	30
Clay	35	10	15	15	35	22
Sand	15	25	25	45	14	40
Clay	20	8	20	10	32	27
Sand	12	25	15	30	17	36
Clay	23	15	30	20	....	19
Sand	25	30	10	35	....	13
Clay	15	20	22	....	....	....
Sand	14	8	75	....	....	....
Clay	....	6	10	....	....	....
Sand	....	20	40	....	....	....
Clay	....	....	4	....	....	....
Sand and gravel	....	....	80	....	....	....
Clay "stiff"	....	....	10	....	....	....
Sand	....	....	60	....	....	....
Clay	....	....	36	....	....	....
Sand	....	....	35	....	....	....
Clay	....	....	15	....	....	....
Sand	....	....	35	....	....	....
Sand rock	....	....	1	....	....	....
	254	262	621	232	210	240

* Gravel.

[a] At 230 feet struck water.
[b] Water at 256 feet.
[c] Gravel, first water at 220 feet; second water at 539 feet, rising to 65 feet of surface.
[d] Water at 212 feet.
[e] Water at 193 feet.
[f] Water at 227 feet.
Location T. and P. surveys.—No. 2, sec. 1, T. 2, B. 81; No. 3, sec. 10, T. 2, B. 81; No. 4, sec. 1, T. 2, B. 81; No. 5, sec. 10, T. 2, B. 81; No. 6, sec. 19, T. 2, B. 81; No. 7, sec. 38, T. 1, B. 81.
In well No. 4, after piercing sand in 28 feet of water, the same sunk to original level. Water in all wells rises from 15 to 20 feet after being struck.
[g] Or gravel.

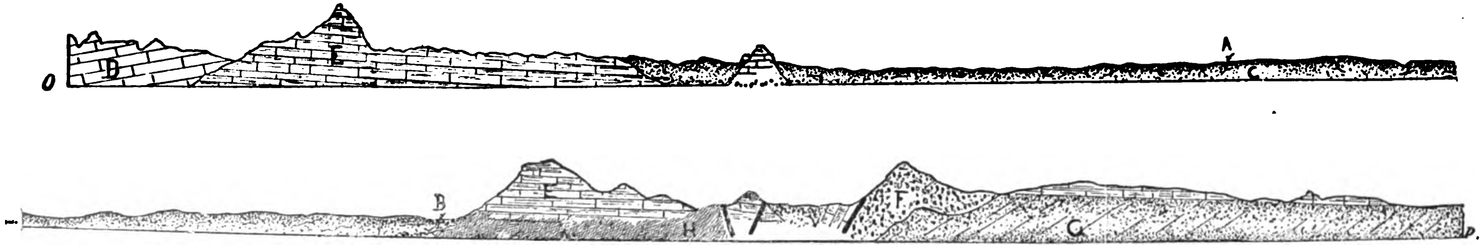
The success of these wells, together with their inexhaustible supply of water, demonstrates the fact that the capacity of the Franklin-Hueco basin formation for water is very great, notwithstanding the slight rainfall and excessive evaporation which has driven the line of visible moisture nearly 150 feet below the surface.

Relatively speaking this basin is one of the great water-bearing areas of the West, where, if irrigation can be profitably conducted by pumping, an agricultural community will eventually thrive. Already several large fruit farms are being irrigated on this basin by means of pumped water, and if they prove profitable there is no reason to suppose but that much of this country, apparently a hopeless desert, will be made into a fertile region.

The Mesilla Basin.—West of the Organ Franklin Range, there is another extensive basin, which is occupied by the valley of the Rio Grande, and extends from near Old Fort Selden to near Frontera, 4 miles west of El Paso. On the west this basin is bounded by the Organ Mountains and other small mountain blocks running north towards the Fort Selden eruptives.

In the basin are situated the towns of Mesilla and Las Cruces, two of the most flourishing places in southern New Mexico, and extensive agriculture is carried on by irrigation from the Rio Grande.

The formation of this basin is the same as that of the Hueco-Franklin basin, and at times no doubt its lakes were continuous with its waters. The river which is in the consolidated mountain rock at Fort Selden, has cut deep into this plain, and much of its waters are imbibed by the



A, Southern Pacific Railway. B, Texas Pacific Railway. C, Post-Cretaceous deposit (no rock struck at 1,050 feet). D, Cretaceous limestone. E, Carboniferous limestone. F, Conglomerate of Metamorphic and Serpentinous rock cemented by ferruginous silico-calcareous matter. G, Red Sandstone. H, Talcose and Mica Schist.

SECTION ACROSS WEST END OF EAGLE FLATS, ILLUSTRATING BASIN DEPOSITS BETWEEN MOUNTAINS. COPIED FROM W. H. VAN STREERNWITZ.

porous formation until it again enters the mountain rock some 100 miles below at El Paso.

The surface character and water experiments conducted in this basin have been ably described in the report of the Senate Committee by citizens, as follows:

> From the lower end of the Jornada at Fort Selden the Rio Grande again broadens out into a beautiful valley. It is a basin in shape. Both to the east and west are the mountains, which close in at Fort Selden on the north, and at El Paso on the south. The length is about 40 miles. The Organ Mountains, 12 miles from the river, from the eastern rim of the basin. It would require a further examination to show if the other conditions of an artesian basin are present.
>
> No deep wells have been attempted. The deepest reported is 65 feet, but from these wells of moderate depth water rises nearly to the surface. The following letter from Mr. John De Meir, a citizen of Las Cruces, shows the experience at that point.
>
> "I am convinced that our valley is one immense artesian belt, and will cite a few cases to confirm it.
>
> "The deepest drive well here is 65 feet, at Col. Albert Fountain's. The water stands at 4 feet of the surface. Maj. Llewellyns well, 700 feet distant and south of Fountain's, is driven 45 feet; water stands at 4 feet. One mile south of his well, McClure Brothers drove down 65 feet; water stood at 4 feet. They broke their pipe and could drive no further. An open well up on the foothills, upper part of town, sunk to a depth of 45 feet, and the bottom being about 12 feet below the valley land, gave a poor supply of water. Mr. Ackenback, the owner, drove a pipe 16 feet in the bottom and it rises in the well and yields all the water they desire. So far the strata here is the same as in California. In driving wells every few feet they strike a hardpan that makes it slow, hard work until it is penetrated, and when passed through it will drive easily till next hardpan is struck. These stratas are from 2 to 4 feet thick, and in sinking open wells it is necessary to use explosives. I have been hammering at the people for the past year to raise funds and give it a trial, and while all are of the same opinion as I am, it is slow work to get them to move in the matter. On the east side are surrounded by a high mountain range 2,500 feet higher than the valley, while on the west we have a high mesa and mountains. At Fort Selden the mountains meet and form a narrow pass worn through the rock, and at El Paso they meet again and form another pass, so that we are truly a basin with a rock pass above and below us. I send a diagram, which may give a better idea of our situation."
>
> Mr. De Mier, of Las Cruces, says: "About 28 miles above here, in upper end of this valley or above it proper, springs crop out at river bank and keep the lagoons full when Rio Grande is dry. Am informed same feature prevails this side of El Paso, Tex., at lower end of the valley. There are immense bodies of water flowing from hidden veins in the Organ Mountains 12 miles east of this point; one in particular is over 50,000 gallons an hour. At the Memphis mine that amount was pumped day and night for over a year. It came in at about 130 feet in the shaft, and only part of it entered the shaft. Mine has been closed down for past six years on account of water. There are a number of springs on both sides of the range, mostly on west side, draining into this Mesilla Valley.

The structure of this valley is also favorable for the imbibition of all the water that falls upon it, or that flows down the adjacent mountain sides, while the presence of the running water of the Rio Grande throughout its length has obviated the immediate necessity of experiments, like those at La Noria which resulted in the discovery of the Franklin-Hueco water bed. There can be little doubt then from the data obtained but that well water can be obtained anywhere throughout this basin.

Covering the artesian possibilities of this region, it can only be said that it presents the same features as the Hueco-Franklin basin, to wit: A sharp topographic slope from the north end, where most of the water is received, to the south, and a general similarity in structure to the conditions of the similar basins of the San Luis and other places.

It may also be added that, extending southward from the Donna Ana to the Florida mountains, there are extensive dikes or walls of igneous matter which are apt to have a negative effect upon artesian principles in the western part of the valley.

The Jornado del Muerto basin.—The western end of the Mesilla basin or plain is terminated by a group of stratified and volcanic hills, which extend westward from the Organs, via Dona Ana and Fort Selden, cutting off the Mesilla basin from that of the Jornado del Muerto, which begins north of this barrier and extends northward for a hundred miles. This is perhaps the most noted of the basin plains, having long been celebrated for its absolute lack of surface water, and lying directly in the track of the ancient Santa Fe-El Paso trail. Its very name signifies the journey of death, and was given it owing to the great difficulty travelers found in crossing it.

The Jornado occupies the country north of the Dona Ana hills from Rincon northward. On the east its limits are the San Andreas and Sierra Oscura, the northward continuation of the Organ range. On the west, by the Sierra de los Caballos and Fra Cristobal, the southern continuation of the Sandvia range. The Atchison, Topeka and Santa Fe enters it at Socorro, northward, and continues upon it to Lava station.

This basin has been described by Dr. G. G. Shumard * as follows:

> It lies east of the Rio Grande and may be described in general terms as a gently sloping plain, somewhat elliptical in form and inclosed on both sides by lofty mountains. This plain extends from near the southern extremity of the Dona Ana mountains, northwest, for the distance of 80 or 90 miles, and varies from 12 to 40 miles in width. Near the southern extremity it is partly interrupted by the Donna Ana mountains, and there its width does not exceed 12 miles; but as we travel north it rapidly widens, attaining its greatest transverse diameter at the distance of 20 or 25 miles; it then gradually diminishes until we arrive at the northwestern extremity, where it does not exceed 18 or 20 miles in width. Throughout the entire length it is marked by a distinct central depression, which, as will be seen hereafter, corresponds pretty accurately with the synclinal axes of the underlying strata.
>
> Wherever examined, the surface formation was found to consist of detritus of rocks débris, in all respects the same as those composing the neighboring mountains from which it was doubtless mainly derived. The precise thickness of this deposit could not be very accurately determined, as only a few natural sections were observed, and these only near the base of the mountains. In two localities its observed thickness was nearly 500 feet.
>
> The two ranges of mountains forming the eastern and western boundaries of the Jornado de Muerto curve gently in opposite directions and are remarkable for their close general resemblances and simplicity of structure. In each we find a gentle slope toward the plain and bold and nearly vertical precipices in the opposite directions. Along their summits are exhibited the sharp and jagged edges of their uplifted strata.
>
> The range of the east varies in width from 5 to 15 miles, and forms a nearly continuous range extending north and south, the entire length of the Jornado, as will be hereafter seen; it is composed principally of upheaved strata of dark gray, blue, and black subcrystalline limestone, dipping west at various angles. Although these mountains have the same general direction, and are apparently continuous with the Organ range with which they have been heretofore classified, nevertheless their general conformation and structures are totally distinct. In no respect is there the slightest resemblance between them, one being composed almost entirely of sedimentary strata, and the other mainly of eruptive rocks.
>
> Upon the western side of the "Jornado" the mountains are interrupted at their northern and southern extremities by broad valleys, the main portion of the range being separated in the one direction from Fra Cristobal Mountain by an extensive volcanic district, and in the other from the Rolledo Mountain by the valley of the Rio Grande and a chain of igneous hills. Although in general appearance very closely resembling the mountains, upon the opposite side of the plain the central portion of this plain is found to differ somewhat from them in composition, the limestone being here overlaid by grits, shales, and sandstones, which altogether present an average thickness of about 800 feet, and are uniformly found dipping towards the east. The length of this portion of the range is from 40 to 50 miles.

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* The geological structure of the "Jornado del Muerto," New Mexico, being an abstract from the geological report of the expedition under Capt. John Pope, United States Topographic Engineers, for boring artesian wells along the line of the thirty-second parallel, by Dr. G. G. Shumard, M. D., geologist of the expedition. (Transactions of the Academy of Science, of St. Louis, Vol. I, 1856-'60, p. 341.)

> Geologically speaking, the Jornado del Muerto may be considered as nothing more than a single trough, composed mostly of limestones, sandstones, and shales, and covered to the depth of 500 or 600 feet with loose detritus.
>
> As this trough throughout the greater portion of its length appears to be entirely free from igneous protrusions, I am of the opinion that an abundant supply of water can here always be obtained by means of artesian wells. The depth to which borings would have to be carried for this purpose can not very readily be determined, as but few natural sections were exposed upon the plain, and these only extended through a portion of the detritus. But as the Cretaceous standstones overlying the shales of the Coal Measures, which would have to be first passed through, exhibit in the mountains, upon the western side of the "Jornado," an average thickness of about 600 feet, it is probable that water could not be obtained at a less distance beneath the surface than a thousand or fifteen hundred feet.
>
> As the "Jornado," besides its lateral slopes, presents a general one from NNW. to SSE., the most favorable situation for the experiment would probably be along the central depression, marking the synclinal axis of the strata, taking care to avoid on the one hand the igneous protrusions, of which the Donna Ana Mountains form a portion, and on the other, the chain of volcanic hills near the northwestern extremity of the plain.

This description is in general correct, but the writer is of the opinion that if artesian water is found it will be in the detrital deposit of the basin, and not in the underlying floor of mountain rock, and at a much less depth than that indicated by Dr. Shumard.

Probable basins of the Pecos Valley.—The Rio Pecos, from the mouth of Delaware Creek to Pecos City, 50 miles, and from thence to an undetermined point some 50 miles below, flows in marls and clays of the typical basin character, which, together with the topographic conformation and well-boring records of the region, lead me to believe that this portion of the Pecos Valley is either another of the Quaternary basins or an allied estuarine formation.

The main escarpment of the Llano Estacado is far east of Pecos City, and the river is in a wide flat or basin some 30 miles wide, from Toyah to Quito, which seems unlike a drainage flood plain. This flat is marked on the east by a high scarp line near Quito, 12 miles east of Pecos City, but inasmuch as the apparent shore-line formations were of the softer Red Beds and plains formations, instead of the harder mountain rock, like that of the other basins, it is difficult to say after my brief studies whether or not it is a true shore line, although I am greatly inclined to think it is. The western shore of this apparent basin is the east of Toyah against the slope of the Davis Mountains.

Both at Pecos City and at Toyah, numerous artesian wells have been found in this alluvial deposit, be it of lake or river origin, which give weight to my hypothesis that these beds are the chief water-bearing strata of the west. These wells also occur under favorable topographic conditions, *i. e.*, at a lower altitude than the shore line of the basin, and are a remarkable demonstration of the amount of water which under favorable conditions can be abstracted from such an arid region, situated as they are, in a district which one would, under the old mountain theory of water, consider most unpropitious.

Mr. Roessler has reported (1890) the following wells from the Pecos Valley:

Flowing artesian wells at Pecos City, Reeves County.

Owner or informant.	Depth.	Bore.	Cost.	Remarks.
	Feet.	*Inch.*		
J. B. Gibson	250	4	$300	9 gallons per minute.
W. S. Marshall	315	3	500	60 gallons per minute, pressure 20 pounds.
Texas Pacific Railway	220	4	440	Water rises 27 feet above ground.
C. H. Merriman	185	3	351	60 gallons per minute.
W. D. Johnson	185	3	....	Do.
Do	185	6	....	Very light flow.
T. M. Clayton	227	3	....	All these wells are bored within a circumference of 2 miles, and all of them have a continuous flow.
Matheson, Cook & Walker	213	3	....	
Gage, Walthall & Powers	250	3	....	
Pecos Valley Land and Irrigation Company.	287	3	....	
Havens, Phillips & Allen	237	3	....	
Juston Robertson	shallower	2	....	
A. T Windom	...do.....	2	....	
W. D. Johnson and C. F. Thomason	235	3	....	
County of Reeves	227	3	....	
Chilton, Bowen, *et al*	....	3	....	

These wells are located on section 40, H. & G. N. surveys, and section 69, block 4, H. & G. N. The water in all of them is slightly brackish, some being better than others; in one or two some saline ingredients. The water, however, is not injurious to vegetation, and in a small way is used for irrigating gardens, though most of it is allowed to run *ad libitum* and make a mud puddle of the vacant town lots.

Flowing artesian wells at Toyah, Reeves County.

Owner or informant.	Depth.	Diameter.	Cost.	Remarks.
	Feet.	*Inches.*		
Texas and Pacific Railway	834	*9 †13	....	300 gallons per minute, or 432,000 gallons per diem.
Do	514	12	....	About 9 gallons per minute. Now being bored down farther.

* Top. † Bottom.

The water from both of these wells is white sulphur with a salty taste, and can be used to advantage for irrigation, as the water does not seem to be injurious.

At Toyah the water is found at 20 to 30 feet. Underneath this, at a depth of about 200 feet, at Pecos, is artesian water under great pressure. Now at Toyah, altitude 2,975, the same water is found at about the same depth and in about the same material, but it is devoid of pressure here. At 832 feet a strong flow (300 gallons per minute) of sulphur water was obtained. (It is claimed that the sulphur came from some higher point in the well and that the bottom water was pure, and that the present outflow is impregnated with sulphur only because the casing was defective.) It is probable that this same water will in all probability be found at Pecos at a similar depth. Adding to the pressure existing at 200 feet, 300 gallons per minute through 3-inch pipe, the weight of a column of 375 (the difference in altitude between Toyah and Pecos) it is easy to presume that at a depth of 1,000 feet artesian wells can be obtained which will flow from 1,000 to 2,000 gallons per minute.

The wells of this subdistrict as a rule are very deep and the water in many of them is practically unfit for use.

It is my opinion that these wells can be obtained over about 100 square miles of this region, from 50 miles north of Pecos City to 50 south, and will prove a great blessing to the region.

It is interesting to note that laboring under the old theory of mountain origin of artesian water Capt. Pope and Dr. Shumard bored their unsuccessful experimental well just north of the Pecos City basin in the hard rock, when if they had left the mountain rock out of consideration and bored 20 miles southwest on the supposed unpropitious plain they would have secured abundant water at shallow depths.

The Eagle Flats Basin.—Another and extensive formation lies between the parallel mountain ranges of the Quitman-Muerto series (which is a continuation of the Hueco series) and the Diablo Davis series. This basin is of irregular area as shown upon the map, and has two principal arms or members, the southwest of which is traversed throughout its greatest length by the Southern Pacific Railroad from the Sierra Blanco to Marfa, a distance of 100 miles, and is known as the Eagle Flats. This is a very narrow basin seldom exceeding 25 miles in width, and like the others is surrounded on all sides by mountain blocks, against which may be clearly discovered the terrace structure of the ancient lake shores. The soil is the same pink tinted gravelly loam of the Franklin basin.

This basin has never been explored for water where it could be most expected, *i. e.*, in its lower and deepest end, but upon the contrary, the Southern Pacific has made several very costly experiments in drilling into the hopeless mountain rocks around its edges. It is my opinion that wells similar to those at La Noria on the Franklin basin will yet be obtained in the now desert Eagle Flats.

From Sierra Blanco this basin sends another arm east and northward, up to the east side of the Hueco series, and west of the Carrizo and Diablo mountains toward the Wind mountains, for an unknown distance; the general outline, so far as I have been able to ascertain by inquiry and observation, being as laid down upon the map. In this portion of the basin there are several salt lakes of small area and extent. The Texas Pacific crosses this portion of the area to eastward of Van Horn, where it crosses out of it through a mountain gap.

Valley of the Salt Lake Basin.—Another vast basin extends along the meridian of 104°, from the southern end of the Guadalupe, north of Wildhoyse station on the Texas Pacific. This basin is about 35 miles in extent northwest, southeast, and about half as wide, and is marked by numerous salt lakes. It is surrounded on the west by the mountain blocks of the Sierra Diablo, on the north by the Guadalupes; and on the east and south by low unnamed mountain blocks. From descriptions this must be one of the most interesting of the great basins, but the writer has been unable as yet to visit it. A few wells are reported.

Basin of the Mimbres.—West of the chain of mountain blocks, including the Florida's and Las Mimbres, the Black Range groups on the east, and the Sierra Bacco, Pyramid, Hatchet, Burro, and Black ranges in the west; there is another vast basin into which drains the river known as the Mimbres and several other typical lost rivers, most of which come from the Mimbres and Black mountains.

This basin with its southern extension—the Florida Plains—includes about fifty townships or 9,000 square miles in the United States and at least as many more in Northern Mexico.

Its surface and formation is composed of the same level topography and lacustral débris as the other basins mentioned, and like them it has a drainage slope southward.

The Atchison, Topeka and Santa Fe, the Southern Pacific, and the Silver City and Pacific railroads, all traverse this valley and meet at Deming, which is situated near its eastern border.

The northern end of this valley receives, relatively speaking, much mountain water from the Black and Mimbres ranges, and, like the Franklin Hueco basin, is characterized by numerous lost rivers. One of these, Las Mimbres, is the most conspicuous of all the lost rivers of the West, and has been the cause of much speculation and wonder. It is a bold flowing mountain stream until it gets well out upon the plain, when it completely disappears by imbibition and evaporation.

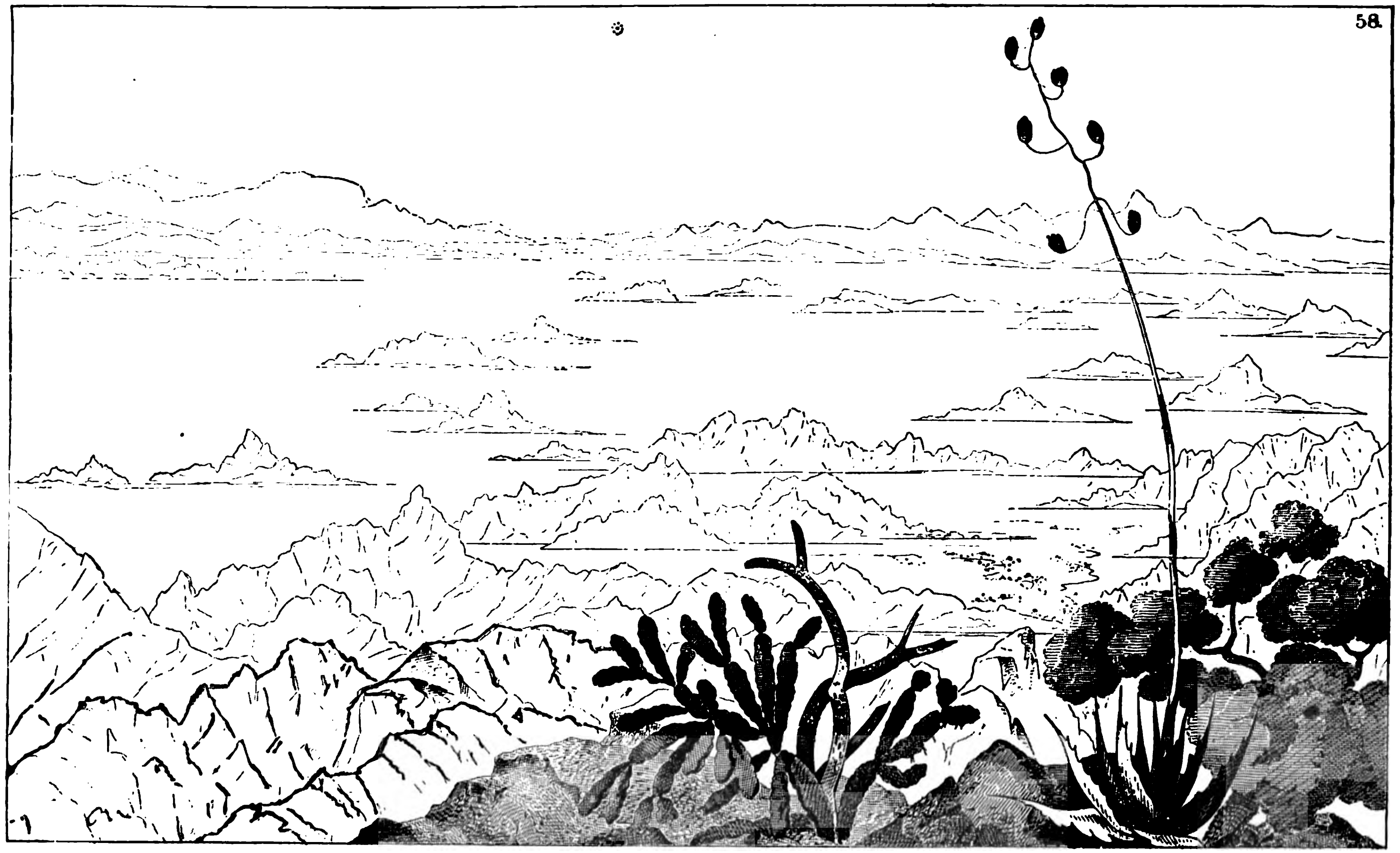
Much of this water, as in the other basins, becomes stored in the sponge-like strata of the old lake formation, and is readily accessible in many places, especially at Deming, where irrigation is produced from this so-called "underflow."

According to the testimony of Mr. Warren Bristol, this county (report of special committee, United States Senate on Irrigation and Reclamation of Arid Lands, Vol. 3, p. 64) formerly appeared before the discovery of this underground water as a barren plain; a desert with nothing but sparse grama grass growing upon it.

> At that time there was no water on this table-land, except occasionally, when the water came down by flood. No water was known to exist there, but there is a region of country from 25 to 50 miles long, north and south, that we know of (and how much farther it exists we do not know) where if you dig down anywhere you will strike water about 50 feet in inexhaustible quantities. To illustrate: At my place I have a powerful windmill, an 18-inch wheel (Holladays). Each revolution of that throws out 100 gallons of water; you can run it up to 160 revolutions per minute. There are only 2½ feet of water in that well, and that quantity can not be lowered with pump. It is so all over the plain.
>
> Deming was a very unpromising place; now it has a great many windmills, and is a pretty place. The change really seems like a miracle. The Southern Pacific Railroad Company was the first to discover this water beneath the surface. Since then it has improved; the whole plain I have described is covered with cattle ranches and the ground is all occupied with pumping machines of this kind to water the cattle. A great deal of money is invested there. The whole plain is taken up. In addition to that, the great waste of water that flows out from the foothills onto the plains could now be collected in immense reservoirs and distributed over the plains for agricultural purposes. The opportunities for that are very great.
>
> I have lived in New Mexico for something over seventeen years, and I regard New Mexico as having one of the most healthful climates on the continent. My experience and observation convince me that the most salubrious region is not high up in the mountains, at an extreme altitude, nor down in the river bottoms, where there is more malaria, but out on the plains. I consider this as good a climate as can be found in the world. Wherever water can be had the soil is wonderful in its productiveness. It is rich in all the elements of fruitfulness. On the plains the greatest drawback at present, in my opinion, to successful cultivation is the strong spring winds, which prevail in every section where there is no wind-break. As soon as forestry is systematically cultivated here, and trees are planted so as to break the prevailing winds, it will be a wonderful country with water for productiveness. The altitude of Deming is about 4,000 feet. It is on the first plain of what we call the Mesa Valley of the Rio Grande. It commences on the high bluffs of the Rio Grande, and is a lovely plain all the way on into Arizona.

In addition to the basins mentioned there are numerous others which it has been impossible to investigate, but which lie mostly beyond the territory of these investigations. Among these are several of minor importance, in the so-called phenomena of Texas, west of Texas Pacific Railway; several in southwestern New Mexico, such as the Playas de los Pina, Valle de los Playas, and others, and several in the mountains of north central New Mexico.

The water conditions of the basins in general.—These vast inter-mountain, plains, or basins, or ancient lake valleys have, until lately, been absolutely void of surface water, and so synonymous with sterility that they have been considered often the synonym of death, like Death's Valley in California or the Jornado del Muerto of New Mexico. That they should now be found to be underlain in much of their area by an abundance of fresh water, is a fact which is of greatest value in the economic conditions of the arid region, where water is worth more than land, and where a drop to even quench the traveler's thirst is usually unobtainable, except in rare localities. The far greater extent of these



Characteristic View of the Basin-Plains of Arizona and New Mexico.
[From Report of Mexican Boundary Commission, 1856.]

basins than the mountains over New Mexico, Texas, and Mexico, seems to have been overlooked or considered unimportant by national surveys, as well as its underground water conditions.

As a rule these basins are surrounded on all sides by blocks, or ranges of high mountains, the blocks usually unconnected and through the passes of which many of these lakes may have been once continuous in some period of their existence, but were not so during the latter days. These mountain blocks are more extensive at the northern border of the basin region, and the precipitation is greater upon them as a rule than upon the intervening plains.

Taking the basins as a whole, I think that from a study of their topographic and geologic features, a few generalizations can be deducted which will be of inestimable value to the future investigators of underground water supply of the region.

These lakes belong to a great area of similar features which exist over northern Mexico and the Southwestern United States during comparatively recent geologic time. This area composed much of California, Utah, Nevada, Arizona, New Mexico, and Texas west of the Pecos, and the Nevada Utah portion has been accurately and minutely described by Gilbert, Dutton, and Russell in the monographs of the U. S. Geological Survey, as the basin region of the United States. These basins, as is testified by all who have visited them, are often dry while frequent storms and cloudbursts can be seen upon adjacent mountains.

These basins, at least in New Mexico, Arizona, and western Texas, although originally horizontal, have all been elevated to the northward, so that old lake bottoms now incline southward, or southeastward at a considerable gradient.

In composition they consist of exactly the same material as the mountains, but under different physical conditions. In the mountains this rock is massive, imporous, and impervious. It was ground up, pulverized, and assorted by the waters before its deposition in the lake basin. This difference in physical condition is radical, and in the consideration of underground waters it is all important. A cubic foot of massive glass would contain little rock water, even if soaked for days, and the mountains are composed of just such material. The same glass if ground to small grains would become porous and absorb into the interstices between them from one-tenth to one-half their volume. The mountain rock was ground before it was distributed over the valleys, and hence, although the same materials as the mountain rock, it has become porous, and, as these old lake sediments, will imbibe and retain the water a hundred fold.

The water falls mostly upon the mountain. Some of it is imbibed by the small patches of soil and porous layers or penetrates the fissures and caverns to be more slowly returned to the surface in after times. A good amount is also evaporated by the wind and the intensely heated rock. Most of the rainfall, however, flows off in the floods down ravines and cañons towards the base level, which is the surface of the basin plain. Upon reaching this, part of the stream is imbibed or drank in by the porous cavernous sands and loosely cemented soil, and a great deal of it sinks beneath the line of saturation, between which and the hard rock floor, upon which the basin formation is deposited, water is stored as shown in the previous figures.

This water of the basins is always available by bored wells, but it may or may not possess artesian pressure, according to its stratification and topography.

If the basin formations are composed of alternations or bands of sand and clays, in other words stratified (and most of them are), and these water strata have inclination, which they usually do, in concave or synclinal nested arrangement, then the stratigraphic conditions for artesian water are mostly ratified, as at Toyah, Pecos City, and elsewhere. If this stratification is more or less concave or nested, and there is a corresponding topographic inclination from the edges towards the center of the basin, or a slope from one end of the basin to the other, topographic conditions for artesian water will also be favorable, and experiments should be tried near the central portion of that end of the basin which is lowest in altitude, provided there are no unfavorable conditions, such as dikes or fissures.

The writer is inclined to the belief that in all of these flats or basins water can be obtained in quantities that will at least do for stock purposes and possibly for limited agricultural use. Everywhere that wells have been sunk (save in the exceptional places such as at the immediate edge or at the higher ends, as at Sierra Blanco) water has been obtained, and at La Noria, 10 miles northeast of El Paso, there are several fruit farms in the midst of the plain being irrigated by water pumped from wells in the basin formation at depths of 200 feet. I have been informed that waters rose 150 feet under hydrostatic pressure above the bottom of a 600-foot well at this place, thus indicating possible artesian pressure at lower altitudes.

In endeavoring to obtain water upon these basins, several important things are to be avoided.

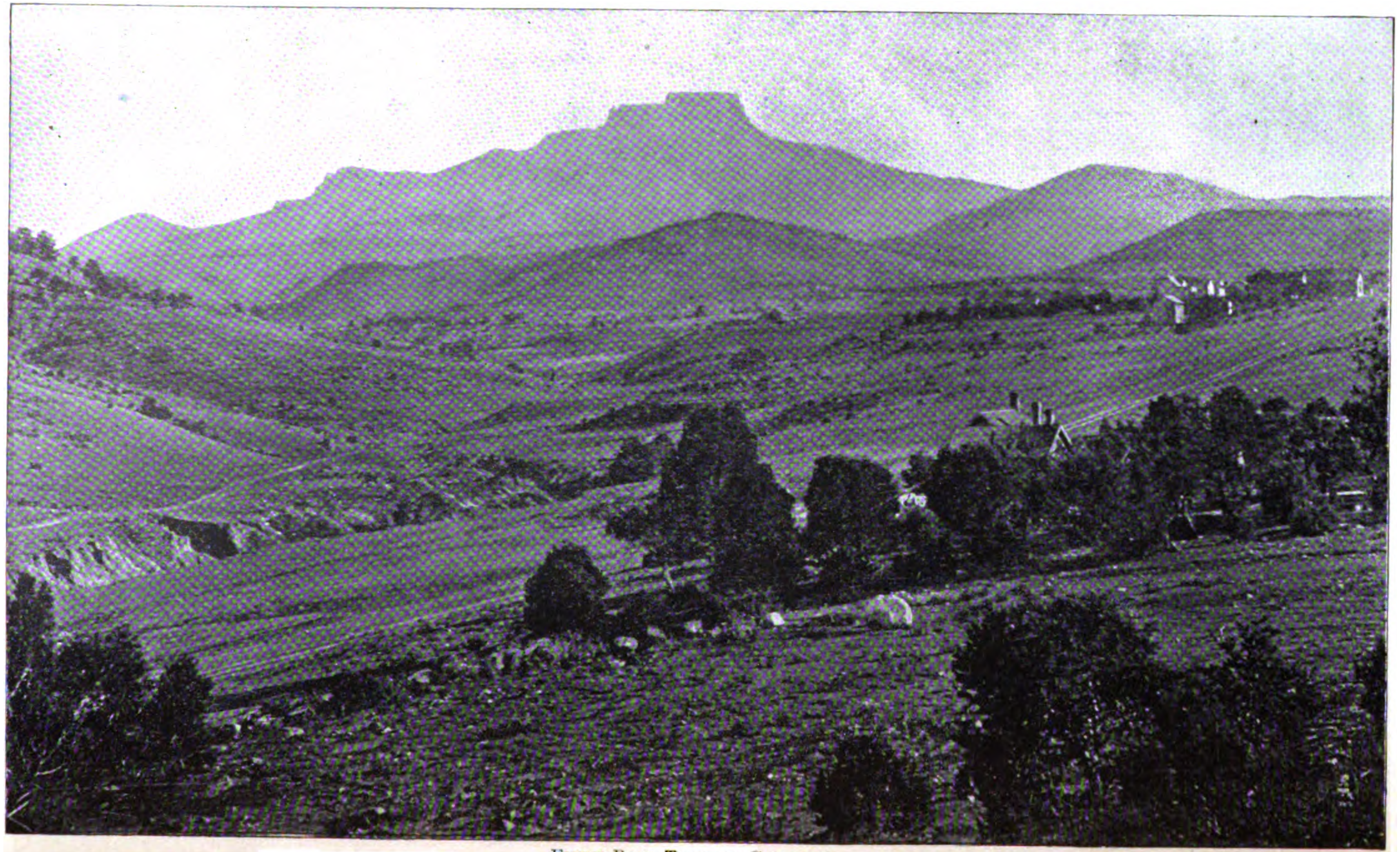
1. Boring too near the edge or perimeter of the basin. Inasmuch as the soil is usually dry for a distance of 50 to 200 feet; and that the floor of the basin formation is composed of impervious mountain rock, the edges of the basin are not apt to be in the saturated portion of the basin formation at all; but the unpropitious formation of the mountain rock will be reached.

2. Boring near the upper or higher end of the basin. Most of the basins are higher at one end than at the other, often by a thousand feet or more. This is a product of the elevation they have undergone since their beginning. It is obvious that the surface water would drain downward and toward the lower portion of the basin, and that the upper end would usually be unsaturated. Many thousands of dollars have been lost by railway companies and individuals by boring for water too near the edge or upper end of these basins and many regions erroneously adjudged void of water on account of such failures.

3. Boring through the basin formation into the mountain rock floor. It has been the experience of most drill holes that it is useless to expect water in the hard rock floor underlying the basin formations, and when this is reached, except when there are very favorable conditions of porosity and inclination, further boring is useless.

The quantity of available water of saturation varies in different basins, and is proportional to the area and rainfall of the surrounding mountains. The San Luis Valley of northern New Mexico is surrounded by high mountains of vast drainage area, larger than the area of the valley. These mountains are covered by snow in winter and have greater rainfall than the mountains of the southward, and the amount of water drained onto and imbibed by the basin is enormous. The Sierra Blanco Basin, on the other hand, is encircled by comparatively low untimbered mountains, upon which there is little precipitation, and no great supply of water could be penetrated.

It is not probable or possible that sufficient underground water is



FISHER PEAK, TRINIDAD, COLORADO.

Showing structure and erosion of Las Vegas-Raton Plateau, the highest block of mountain being of lava.

stored in these basins for a large or extensive agricultural population, but when it is remembered that water for even the passing traveler is lacking, and that many of those vast areas of land are almost absolutely uninhabited for want of water, even a single well to every 20 square miles would be of more value to the region than a vast lake of water is now in the humid regions; and it is safe to predict that in a few years there will be hundreds of wells to one at present, around many of which will be not a few valuable irrigated farms.

The possible success of artesian water in these basins is also suggested by the fact that numerous artesian wells have been struck in similar basin deposits in California, Colorado, and Utah, and as I have been informed in the basin valleys of Atacayma in Peru and the valley of Mexico. In fact no case of artesian water having been struck in the arid region from any other supply than these unconsolidated basin or allied deposits has ever been reported south of Dakota* and west of the Pecos.

In fact the newer deposits, whether lacustral, littoral, or fluviatile, have ever proved the most profitable source of artesian water in this country, even in the humid region, as at Memphis, where magnificent wells are secured from the Orange sand and bluff deposits. A noteworthy fact also about many of these wells, as at Roswell, N. Mex., Memphis, Pecos City, and elsewhere, is that they occur in regions which under the old theories of upturned mountain rock, synclinal basins, etc., would have proven entirely unpropitious.

IX.

WATER CONDITIONS OF THE MOUNTAIN REGIONS.

The vast area discussed in this paper is preëminently a region of plains, the mountain proper forming but a small proportion of the whole, and of much less consequence in relation to underground water supply than is popularly supposed.

There are only two classes of mountains proper within the region, those of the Wichita and Arbuckle groups in central Indian Territory and the isolated basin ranges of the Trans-Pecos region.

In the popular classification every butte, mesa, hill, and escarpment is termed a mountain, but nowhere east of the Pecos, except in Indian Territory, is there a true mountain, or protuberance, which is the product of the folding or other distortion of the earth's strata. The so-called mountains of central Texas are buttes and mesas, composed of remnantal patches of horizontal strata, described in our chapters on the Grand Prairie and Central denuded region. The alleged mountains of Burnett and Llano counties are likewise mostly of this type and occupy an erosion valley in the plateau of the Grand Prairie.

The true Rocky Mountains constitute the western limit of this investigation, and it is a current supposition that they are the receiving area for all the underground water between them and the Gulf.

Although the most conspicuous feature in all North America, topographically, the southern extent and limitations of the Rocky Mountain ranges have been poorly defined. Their eastern border or foothills, where they join the plains, north of Santa Fe, N. Mex., to the British line, is unmistakably one of the sharpest and best known features of our country, but no geographer has yet defined their termination south of Santa Fe, and the numerous but entirely different mountains of the basin regions of New Mexico, west Texas, and old Mexico are always confused with them.

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* The Dakota artesian basin is in a semihumid region, though it is probable that it will be extended westerly into the arid area.

Prof. J. J. Stevenson, in his valuable report upon the geological examinations in southern Colorado and northern New Mexico, during the years 1878–'79, has admirably described the Rocky Mountains near their southern terminus and shows their type of structure along their eastern front, from Gallinas to Pueblo, to consist of excessively folded and broken (faulted) strata, conforming to the popular description of having been "upturned."

South of the latitude 25° 20′, he says: "The region is a vast plain cut into mesas, which Prof. Newberry identifies with the Llano Estacado or Staked Plains of Texas," but which in fact should be classified with the plateau region to the west. Towards the south and southeast the dips of this plateau are very gentle, for the most part southward; towards the Rio Grande the plain is broken by the basins and "lost ranges," of which the Placer and Sandia mountains may be taken as types. These short isolated ridges lie west of the Santa Fe axis, and seem to bear no relation to that disturbance whatever. The Archæan area of the Santa Fe axis ends abruptly at about 9 miles north from Gallinas, and a fault is easily recognizable along its eastern side.

South of the Plateau region which encircles the southern end of the Rockies, the country is that of the basin region elsewhere described, consisting of vast basin plains, surrounding isolated and lonely mountain blocks. The mountains are not part of the plains, as in the Rocky Mountain and Plateau-regions, nor are the strata of the plains associated with them or bent up at their edges as geologically and popularly supposed, but a newer and later deposit is laid down against them and is composed of débris of the mountains (see Pl. I, Fig. 6).

The foothills or hog-backs, consisting of vertical strata which accompany the whole front of the true Rockies, likewise end with them.

Many of these mountain blocks have no names at all although large in size. The following, however, are the most conspicuous:

In New Mexico: The Sandia, Organ, Oscura, Jiccarillas, Florida, San Andreas, Guadalupe, and Sacramento.

In Texas: The Franklin, Hueco, Guadalupes, Diablo, Davis, Van Horn, Carrizo, Los Chisos, Sierra Blanca, Apaches, and Santiago.

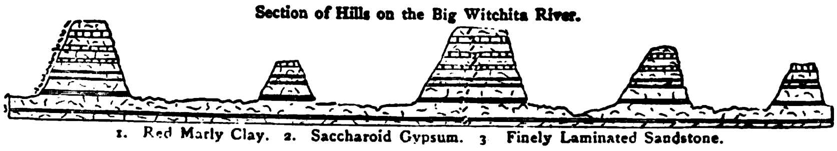
In northeastern Mexico: Juarez, Sierras Rica, Blanca, Frailes, Hornigas, Cuervas, Pinto, De Aire, Del Carmen, Los Burros, Menchaca, Apaches, Picochos, Gomas San Marius, Azul, Lampasos, Trinchera, Fragna, Catorces, and many others.

Nearly all of them consist of elongated masses, extending approximately north and southward, and are mostly composed of hard, impervious quartzites, limestones, and igneous rocks, which have little capacity for imbibition of rainfall, the latter usually flowing away rapidly upon the adjacent basin plains.

The Guadalupe Mountains, which are the most eastern of the groups, are somewhat different and are composed mostly of hard Carboniferous limestone, the water conditions of which are discussed in another chapter.

This group corresponds more to the strike of the main Rocky Mountain axis than any of the others, but they are entirely isolated from them.

Section of Hills on the Big Witchita River.



1. Red Marly Clay. 2. Saccharoid Gypsum. 3 Finely Laminated Sandstone.

[After Shumard.]

The great height and conspicuousness of these mountains, and the excess of precipitation upon them, together with the old superstition that upturned mountain strata are the source of all artesian waters, has led many people to believe that from them alone must be expected an artesian supply. Following this belief, thousands of dollars have been expended, especially by the Southern Pacific Railway Company, in drilling for water at the base of these mountains, while the Government experiments under Capt. Pope were made upon the same hypothesis.

A brief examination of the structure of nearly any of these mountain blocks should dispel the idea that they can ever be the source of great artesian supply. Not only are the rocks impervious to moisture, but the stratification is excessively inclined, and broken by the frequent dykes of eruptive material, which would prevent the transmission of water. With the exception of the cavernous limestone region of the Guadalupes, there are few running springs in all the great territory covered by these streams. No better proof of the unfavorable artesian conditions of these mountains can be given than to cite some of the numerous failures which have resulted.

No idea can be more fallacious than the one generally entertained that the underground waters of the Texas-New Mexico region are in any manner supplied by the Rocky Mountains, for the geological structure is such as to absolutely prevent such a possibility, for the great fault lines and valleys of erosion of the foothills break the continuity of stratification and make such underground transmission impossible. The only water from the Rocky Mountains that reaches the regions under discussion is the surface drainage of the Rio Grande, Pecos, and Canadian.

The Mountain masses of the Basin range are equally unimportant relative to the water supply, although likewise erroneously considered as the source of much underground water.

These isolated ranges, which succeed the Rocky Mountains toward the south, are numerous and of vast proportions, occupying the whole of the country of northern Mexico and the United States from the Pecos to the Sierras, and constituting with the intervening plains the great Basin region of North America, the isolation becoming more and more complete to the southward and the basins more extensive. These mountain blocks, with their accompanying basins and aridity, extend southeastward in Mexico almost to the Isthmus, the Rio Grande below the mouth of the Pecos approximately marking its eastern border.

The first and most conspicuous of these were the Government experiments under Capt. Pope and Dr. G. G. Shumard, in 1858. They selected a site in the Pecos Valley, 8 and 14 miles east of the river, near the Texas New-Mexico line, beneath which they had determined the mountain rock of the Guadalupes to extend. After boring 850 feet, and reaching far down into the mountain limestones, the wells were abandoned as failures.

The Southern and Texas Pacific railways had spent thousands of dollars in seeking water in the Trans-Pecos region, and in every instance where they penetrated the harder or mountain rock their experiments have proved failures, as will be seen in the statistics from Mr. Roessler's report, and in no case were flowing wells obtained.

THE RATON LAS VEGAS PLATEAU.

The general conception of the Rocky Mountain region, based upon the familiar conditions seen at Denver, is that the plains formation extends to the base of the mountains, and that its strata incline coastward or away from the mountains, affording ideal conditions for the transmission of Rocky Mountain water to the whole of the coastward country.

South of the Colorado line, however, in northeastern New Mexico and to some distance north of Trinidad, exactly the opposite condition exists, for around the southern end of the Rocky Mountain front there remains a great level or shoulder, known to the westward as the Plateau region of the United States, to which this Raton Las Vegas plateau is analogous, if not a part.

For the region in northern New Mexico, lying east of the true Rocky Mountains and west of the Llano Estacado, approximately the region south of the Purgatoire and north of the Gallinas, I am obliged to use the above name in distinction from the surrounding country. This district embraces the buttes and mesas known as the Raton Mountains, Fishers Peak, the Mesa de Maya, and many other remnants of the former table-land, which mark the whole region, and in addition the plains of erosion upon which they stand. The cities of Trinidad, Folsom, and Las Vegas may be considered as marks along the northern, eastern, and western boundaries, respectively, while Raton Springer, Maxwell, and other points along the Santa Fe road between the Purgatoire at Trinidad and the Pecos are located upon it.

Its southern boundary is the superb Corazon escarpment of the Canadian Pecos Valley (see chapter on Red Beds), which runs eastward from the Pecos, at Pecos crossing to near the Texas line. This escarpment, as shown in the topographic maps, is over 1,800 feet in height.

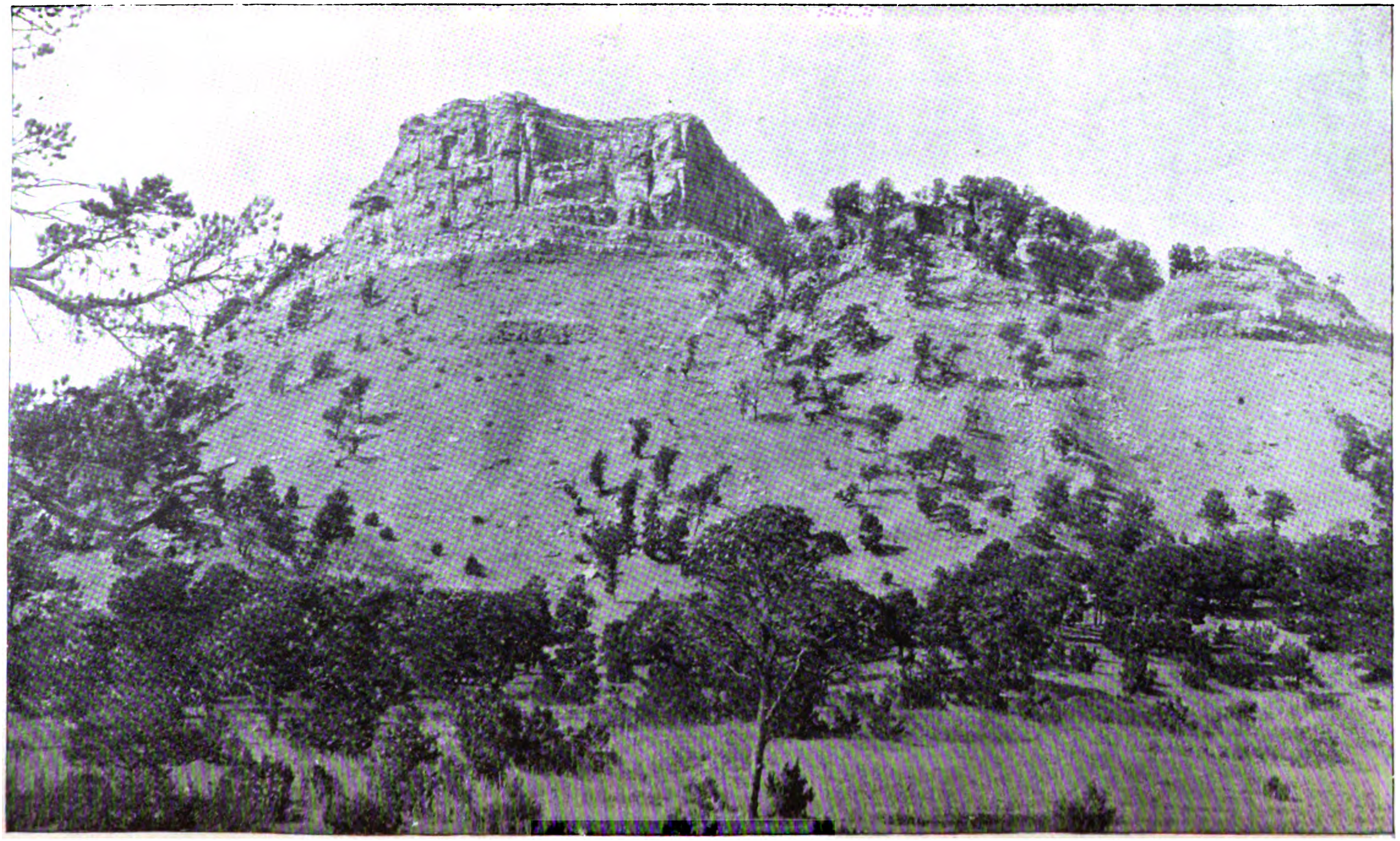
The western border is the foothills, or "hog backs," of the eastern front of the Rockies. The northern border from Trinidad to Folsom is the north escarpment of the so-called Raton Mesa, which is followed by the Denver and Fort Worth Railway. The eastern border is less conspicuous, for it is the base-leveled shore line of the Llano Estacado formation.

This vast area stands out from the Rockies as a bench or shoulder above the level of the plains and surrounding erosion valley, extending some 200 miles to the east.

It is the remnant of a great plateau which existed around the southern end of the Rocky Mountains before the Llano Estacado (Miocene or Pliocene) epoch, the great mass of which has been degraded by the erosions of Tertiary and Quaternary time; the shore line of the old coastal plain now represented in the Llano Estacado having benched its present boundaries and removed much of its mass, which is deposited in the Llano Estacado formation. The later Quaternary erosion has still further degraded the plateau, and reduced its thickness and extent.

This region possesses a diversified surface aspect, consisting, however, of plains upon which stand great mesas of sedimentary rock sheets, often capped with lava, like Raton Mountain and Fishers Peak—remnants of the great erosion the region has undergone in Tertiary and Quaternary time. As a whole, however, it is a series of plains produced by degradation from one harder plain of stratification to another, from the Fishers Peak basaltic sheet to the Laramie sandstones, and from these to the flaggy limestone layers of the Colorado shales, as at Springer and Las Vegas, and from there down to the basal Dakota sandstones, where the latter are cut through, as in the Canadian Cañon, at the Corazon escarpment, the Red Bed floor is always reached.

The plateau or shoulder as a whole is a product, then, of the unequal



SIMPSON'S REST, TRINIDAD, COLORADO.
Showing remnant of Raton Plateau from which lava sheet has been eroded.

erosion of the subhorizontal beds of the Upper Cretaceous from Laramie to the Dakota sandstones down to the Red Beds, inclusive, which are here included between the Red Bed floor and the Fishers Peak basalt. This erosion from top to bottom, via the successive plains of stratification, has partially removed more than 5,000 feet in thickness of sedimentary strata; and there is no evidence that the region has ever been submerged since Cretaceous time, either by the Llano Estacado shore line or the basins mentioned elsewhere. In fact it was the stream-worked land whose débris furnished much of the sedimentation for the rocks of the last-mentioned periods.

Concerning this region Prof. Newberry has said: "The vicinity of Raton Mountain has, in former times, been the theater of violent and wide spread volcanic action. At that time numerous mountain masses and subordinate buttes of traps were thrown up and floods of lava poured out, covering an extensive area in their vicinity. During this period of violence the Cretaceous rocks were locally much disturbed and metamorphosed, and the lowest members of that series elevated to, and perhaps far above, the surface of the ocean. At some time subsequent to the period of greatest volcanic activity, and yet apparently before the fires in the great furnaces were entirely extinguished, the Tertiary strata began to be deposited in the depressions and over the irregularities which then existed on the surface."

The structure of this shoulder is also unique, in that its strata incline towards the Rocky Mountains axis, and not away from it or against its own topographic slope, as can be seen at Trinidad and Las Vegas. (See profile.)

This structure, it will be seen, is inimical to favorable artesian conditions in most of the area, although the foundation of the whole region is the great water-bearing Dakota sandstones, and the testimony of the following drill holes bears out this proposition: At Trinidad an experimental well has been sunk over 2,000 feet, without reaching the sandstone or having a perceptible rise of water. Near Las Vegas, on the southern side, a similar depth was reached but no flow. At Springer, however, a slight flow at shallow depths was met, which is entirely due to local variations. These shallow wells may be possible in other places.

THE MALPAIS REGIONS OF NEW MEXICO.

The occurrence of intrusions such as impervious igneous rocks as dikes, lava flows, cinder cones, volcanic necks, etc., are frequent in New Mexico, the former being especially numerous in the Raton Las Vegas Plateau and in the mountains of west Texas, and the latter along the great fault between Austin and Del Rio. It is generally conceded that dikes are more or less fatal to artesian conditions, breaking the continuity of flow, and that craters' necks and other volcanic items are almost equally injurious to the prospects of water. By far the greater portion of the region east of the Pecos discussed in this paper, however, are free from them. (Figs. E and D, photos.)

Besides the igneous rocks of the mountain proper, large areas of the plains and basins of New Mexico and Mexico, but not in Texas, are covered by volcanic flows of lava and basalt hundreds of square miles in extent. In many cases these are accompanied by cinder cones or craters; in others they are fissure extrusions, and in others the source of the lava flows have not been determined.

Of these sheets there are two distinct types: First, those of more recent age, which have neither been covered by subsequent sedimentation nor seriously degraded by erosion; secondly, more ancient and partially covered or eroded lava sheets of the plateaus.

The oldest class of these sheets are extrusions from the mountain strata, the extension of which towards the plain has been entirely degraded or which never reached them. In this older class are also true lava sheets or flows, which have been so much destroyed by erosion or buried beneath later sedimentation that only fragments of the original flows are now preserved or exposed. This class of eruptives occur in the great cap rock of the Raton Plateau.

The recent sheets are especially conspicuous in the vicinity of many of the ancient lakes' basins previously described; the proximity suggests that there is a close relation between them in age.

The Raton Las Vegas Plateau was originally capped by a vast sheet of basalt lava, which is still the determinative or initial point in the erosion plain of that vast region, but which has been mostly worn away. It still surmounts Fishers Peak, south of Trinidad, and the great Mesa de Maya, extending 50 miles east of there. It also caps the mesas and vast areas to the southward as far as Las Mora Creek. This malpais sheet or sheets must cover hundreds of square miles.

At a lower altitude and apparently of later age, along the eastern border of this ancient basaltic flow, at its contact with the Llano Estacado formation and in the vicinity of Folsom, there is a group of volcanic craters composed of cinder cones from 100 to 2,750 feet in height above the plain, from which have been extruded vast sheets of lava and basalt, covering the country for miles around and extending more or less irregularly from Folsom to Rabbit Ear Mountains, near the Texas line, and north and south of the road about 50 miles, partially covering an area of 1,000 square miles. The most conspicuous of these craters is Mount Capulin 6 miles south of Folsom station. This is a beautiful cinder cone, rising nearly 3,000 feet above the railroad, with a vast crater at its top nearly a mile in diameter, slightly broken down on its western side; from the summit of this can be seen many lava flows. To the southward from 6 to 20 miles are several similar craters, while to the northward are several smaller ones.

These are the most eastern known of the western United States region, and their occurrence at the contact of the great Llano Estacado shore lines and the Raton Plateau are interesting facts.

The cinder cones are clearly of a more recent origin than the adjacent basaltic cap of the Raton Plateau, for they are situated in an eroded valley, between the main mesa and an outlier, the Sierra Grande, (alt. 10,000), and at a lower altitude than either of them. They are also apparently more recent than the late Tertiary deposits of the Llano Estacado, the original surface of the lava resting upon the latter, and not covered by it except in case of the wind-blown débris.

These lava sheets are locally known as malpais. Most of these are vast areas of level rocky desert, absolutely void of economic value, except for grazing lands for sheep and goats, and should be considered as absolutely irreclaimable.

The Cimarron River, which rises in the vicinity of Folsom, has its source in springs from the Laramie sandstone beneath the Capulin and Huerfano lava flows.

The springs are as follows: South of town, one quarter mile northeast of the twin crater, there is a fine spring flowing from a pipe. Below the hotel there is a large spring in the cañon. Three miles below the town the Cimarron falls over lava beds. Two hundred yards below these falls is the largest spring in all the valley, flowing a current 6 feet wide and 18 feet deep. One thousand acres are irrigated from this water. In Oak Cañon, north side of the mountains, there is another large garden irrigated by spring water. Much of this water is derived from the snowfall.

Leaving the Capulin crater, let us proceed southward along the margin of the great basins, and see other similar features. For 200 miles no more of these are encountered until we reach the head of the Franklin Hueco Basin, between the San Andreas and Gaudulupe Mountains, on the stage road from Socorro to Fort Stanton. Here, again, there is a great area of malpais lava, which is a terror to the traveler and barrier to the development of the country which it covers.

Since this chapter was begun Mr. Ralph S. Tarr has published* such a good description of this region that I quote here. He says, in substance:

> Fifty miles east of Rio Grande, between Carthage and Fort Stanton, is a flow of basalt bearing every evidence of being very recent. The point of extrusion is a small cone standing at the northern end. The flow is situated in a basin of interior drainage almost completely inclosed by mountains. The basin, which varies in width from 10 to 30 miles and has a north and south extension of fully 100 miles, is bounded by the Jicarilla Mountains on the east, the Hueco and El Paso on the south, and the Organs and San Andreas on the west. The area of flow exceeds 1,000 square miles. On the foothills of the mountains are quite distinct benches, which, with other evidence, prove this basin is the site of one of the Quaternary lakes, of which there are others in the vicinity.
>
> The loose gravels of the basin quickly absorb all the moisture which falls upon the surface, and the mountain torrents rarely escape far into the plain before being absorbed. A few newer brooks enter from the White Mountains on the northeast side, and they also sink into the soil a few miles from the outlet.
>
> The elevation at the northern end of this basin† is 5,360 feet, and at the southern 4,100.

The Dona Ana—Fort Selden flow.—The northern end of the floor of the Mesilla Valley is covered by another lava flow, through which the railroad cuts at Fort Selden. Pidocho Peak and several others, some 10 miles west of Messilla, are volcanic cones. Of these Dr. G. G. Shumard says:

> From the character and general appearance of these cones and lava streams I am disposed to ascribe their origin, to a comparatively recent geological period. They form part of an extensive volcanic chain, which may be traced north and south, for several hundred miles.

Continuing southward another region of craters, and flows occur south of the Southern Pacific, and west of El Paso about 30 miles. Here the conditions are similar to the others, the cones and lava flows being situated in the floor of the ancient basins.

The lava station sheet.—The northern end of the Jornado del Muerto Basin is also occupied by a great lava sheet 12 to 18 miles in area, or 96 square miles.* This, too, is alleged to have come from a crater about 10 miles east of the railroad, and bears the same intimate relations to the basin floor as the other crater flows mentioned.

Another crater flow upon the floor of the basin is about 30 miles northwest of El Paso between Aften and Aden station, where there is an alleged cone of great magnitude, from which a narrow stream of lava flows southeastward about 20 miles.

There are other areas in New Mexico of volcanic lava, notably that south of Grand Station on the Atlantic and Pacific Railway.

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*A Recent Lava Flow in New Mexico, by Ralph S. Tarr, Am. Naturalist, 1891.

†This basin is the head of the El Paso or Franklin Hueco basin described on a previous page.

In Trans Pecos, Texas, no true lava flows or craters have been described, although many igneous sheets occur in the mountains. Prof. Von Streeruwitz says in his report on this region that:

> Volcanic rocks are represented by lava, compact and cavernous, basalt, basaltic wacke, obsidian, retinite, and trachytic rocks in the Quitman, Sierra Carrizo, Eagle, Van Horn, and Davis, Viejo, and Chinatti Mountains, and probably at least as dikes in the Guadaloupe, Franklin and the mountain ranges not yet examined.

The relation of the cinder cones and subrecent flows to those of northwestern New Mexico and Arizona, I can not state from personal observation, but there is no doubt that there are some common features between them.

Proceeding southeastward into Mexico they still continue and in cases exhibit evidence of activity, increasing southward toward the neck of Mexico, where the present epoch seems to be but a southern continuation of the volcanic and lacustral conditions, which so recently prevailed over the basin region.

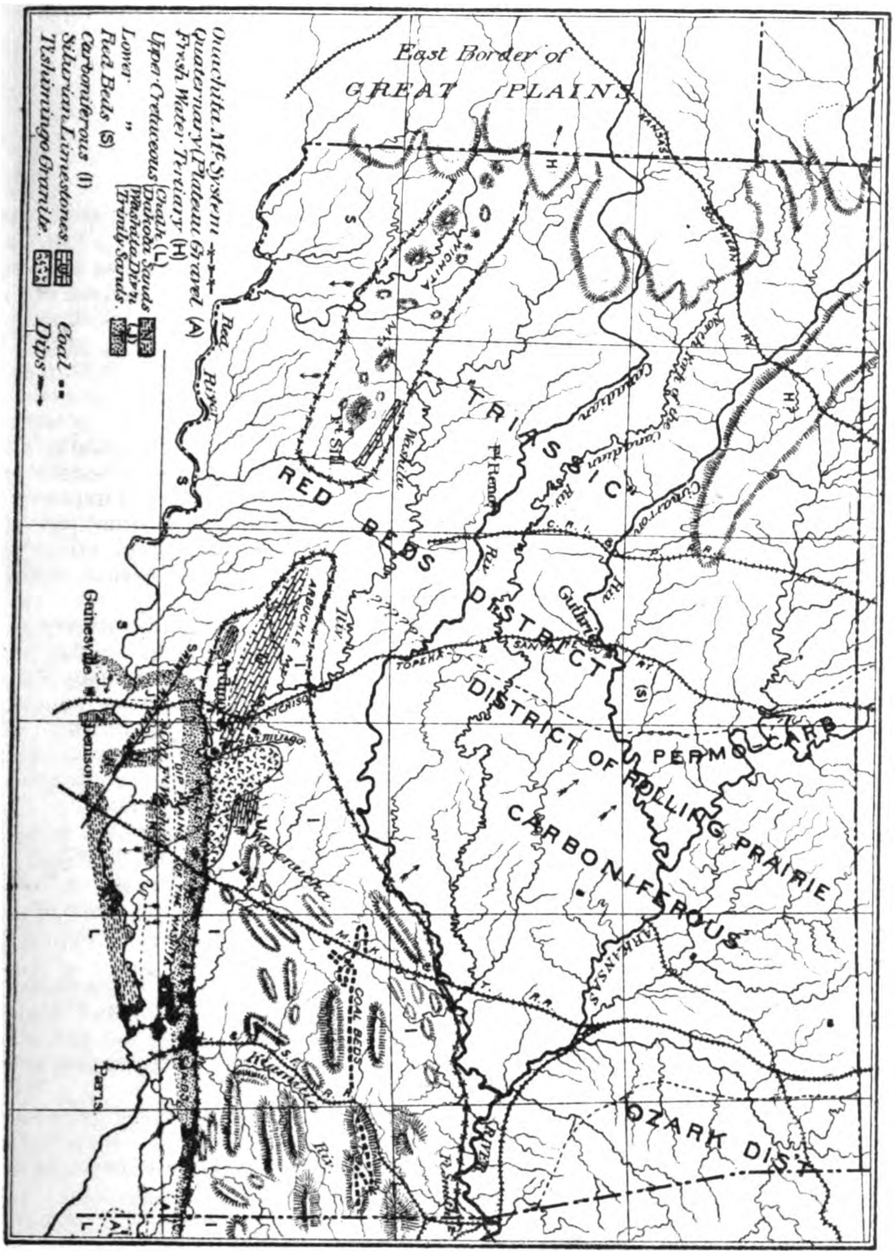
The fact that these cinder cones and lava flows occur in the floor of the Quaternary lake basins, or as in the case of Capulin area, upon the edge Llano Estacado deposits, is indicative of their recent origin, and future investigations will show an intimate connection between the drying up of the basins, and the activity of these volcanoes, although some of our ablest geologists do not believe in this relation.

It is also evident from the investigations that eruptive activities have occurred in the Texas, New Mexican region, from Cretaceous to present time, and at least three well-defined epochs, are at present recognizable, which may serve as an aid for future observations, to wit:

1. The Austin Del Rio system of Shumard Knobs, ancient volcanic necks or laccolites bordering the Rio Grande embayment begun in Cretaceous time, and the lava sheets of which have been obliterated by erosion.

2. The lava flows of the Raton system, which are fissure eruptions of Tertiary time, and which are only partially removed by erosion.
3. The cinder cones and lava flows of the Capulin system, late Pleistocene time, which still maintain their original shape and extent.

Water conditions of the Malpais region.—Igneous rocks possess small capacity for imbibition and transmission of water except through means of joints and fissures between them and these are very few. Even when cellular or scoriaceous there is usually no free connection between the cavities, and hence the honeycombed feature is of little value. In fact they are characteristic of aridity, and in themselves are of little value as water-bearing factors except where they may protect from evaporation some underlying saturated porous sheet, which condition exists in many places throughout the Raton Las Vegas Plateau and at Folsom, where the Malpais rests on porous sandstone from which occasional springs issue. In general they are not favorable to artesian development.


East Border of
GREAT PLAINS
RED BEDS DISTRICT
TRIASSIC
DISTRICT OF ROLLING PRAIRIE
PERMOCARB
CARBONIFEROUS
OZARK DIST
ARKANSAS
ARBUCKLE MT
WICHITA MTS
Ft Sill
Ft Reno
Washita
Canadian
North Fork of the Canadian
Cimarron
Guthrie
Red River
Kiamichi R
COAL BEDS
Paris
Denison
Gainesville
Ouachita Mt System
Quaternary (Plateau Gravel (A)
Fresh Water Tertiary (H)
Upper Cretaceous (Chalk (L)
Dakota Sands
Washita Div'n
Trinity Sands.
Lower "
Red Beds (S)
Carboniferous (I)
Silurian Limestones.
Tishimingo Granite.
Coal
Dips

X.

WATER CONDITIONS OF OKLAHOMA AND INDIAN TERRITORY.

The Indian Territory, including Oklahoma, may be provisionally divided into three parallel east and west belts, each containing a marked diversity of geologic structure and corresponding topographic expression.

The northern or Cherokee-Oklahoma belt includes the country north of the Canadian; the greater part is prairie with spots of timber, decreasing in density toward the west. This belt may be subdivided into three districts: The eastern or Cherokee, the middle or Oklahoma, the western or Arapaho. The Cherokee division, with the exception of a small area of Ozark hills in the northeast corner, is mostly composed of carboniferous rocks, with an undulating topography similar to that of southeast Kansas, and lying wholly within the humid region. The Oklahoma section is a typical Red Bed region in its western half, with undulating prairies and soft disintegrating structure. It is well watered by streams and surface wells. The Arapahoe division is the ragged eastern border of the great plains country, with its charateristic fresh water deposits of sands and grits occupying the flat divides, as recently described in the adjacent west Kansas region by Prof. Robert Hay.[*] And in the accompanying chapter on the Llano Estacado:

Concerning the Indian Territory I have recently published the following description:[†]

> These plains are the newest or culminating formation in western Texas, Kansas, and Indian Territory; they are now slowly receding westward because of the head water erosion of the streams that indent this eastern border, and in this manner the underlying structure and topography are revealed. The northern belt of Indian Territory distinctly belongs to the Kansas division of the United States.
>
> The middle or mountainous belt lies south of the Canadian Arkansas River. A mountain system traverses it from east to west and marks the great barrier between the upper Mississippi Valley and the Texas-Arkansas regions of the United States.
>
> The third and southern belt, the description of which must be left to a future paper, includes the région between the mountainous belt and Red River. It is the northern termination of the Texas region of the United States. It includes many topographic and geologic features which are the result of neozoic sedimentation against the southern border of the mountains.
>
> ### THE MOUNTAIN REGION OF CENTRAL INDIAN TERRITORY.
>
> With the exception of the Ozark hills in the extreme northeastern corner, the mountains of Indian Territory are the direct westward continuation of the Ouachita system of mountains which has been described[‡] as the mountainous area between Hot Springs, Ark., and the Staked Plains of Texas, including the various points known as the Poteau, Seven Devils, San Bois, Shawnees, Jacks Fork, Black Fork, Winding Stair, Sugar Loaf,[§] Cavenal, Stringtown Hills, Limestone Ridge, Potato Hills, Arbuckles, Wichitas, Navajoes, and other mountains. These mountains are south of the Arkansas-Canadian drainage and must not be confused with the Ozarks of southwestern Missouri. Dr. J. C. Branner's coming report will doubtless give us needed light on this relation.
>
> The mountain belt has three distinct subdivisions: (1) An eastern, or Arkansas; (2) a central, or Chickasaw; (3) a western or Wichita. Its areal extent may be compared to an arch whose apex is southward, as marked by the course of the Canadian, Arkansas, and Red River drainage; its eastern member in Arkansas and the Choctaw nation is a forest area of vertically folded Carboniferous shales and sandstones resembling the Appalachian country; the western member in the Chickasaw and Co-

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[*] See Bulletin 57, U. S. Geological Survey.

[†] See notes on a reconnoissance of the Ouachita Mountains of Indian Territory. American Journal of Science, August, 1891.

[‡] Arkansas Geological Survey, 1888, Vol. 2: The Geology of Southwestern Arkansas, by Robert T. Hill.

[§] Near Fort Smith; not the Cretaceous butte of the same name east of Caddo.

manche nations is a mostly treeless region, and consists of low folds of hard white and blue Silurian limestones and eruptives; the keystone or central Chickasaw region consists of an area of granite and Silurian limestones north of Tishomingo.

The most marked feature of these mountains is the excessive compressed and vertical folding which the whole region has undergone, and the displacement of these folds by a lateral dislocation which has squeezed them into S-shaped flexures. So excessive is this folding that every stratum in the mountain region south of the coal fields can be said literally to be standing upon its edge as shown in the figures. This system of folding is complicated and the writer has not had time for minute study necessary to interpret it. In general, two great trends or strikes are conspicuous. The first and oldest is about 25 degrees south of west; this is frequently dislocated by an apparently later movement resulting in northeast and southwest trends, all of which are accompanied by overlapping and lack of continuity. The direction of the folds has a marked effect on the political features of the region, all lines of transportation and public highways practically following the valleys of erosion in the trend of the folds.

The coal fields, for which the name Fort Smith-McAllister area is most appropriate, are of great commercial importance, for they are the chief source of fuel supply for the Arkansas-Texas area. These extend along the northern border of the mountains and are terminated on the southwest by the Silurian and granite field of the Tishomingo district, which are an apparent barrier between this and the Texas-Ardmore coal field.

The Arbuckle Mountains constitute a great and wonderful development of the Silurian system, although this has not been hitherto appreciated, and afford a superb example of folded structure. This folding is beautifully shown in the valley of the Washita, which has cut a deep and tortuous water gap through these mountains, where, unobscured by forest growth, fold after fold of the stratified limestones and shales appear in startling boldness. Several journeys through this gap only increased the appreciation of the greatness of the task of thoroughly delineating the section, the complexity of which may be inferred from the accompanying figures.

West of Duncan the limestone hills are buried beneath the red beds for 20 miles, but again appear in the neighborhood of Fort Sill, forming a low ridge north of and parallel to the Wichita Mountains, as is explained later.

Section across Indian Territory from south to north along Atchison, Topeka and Santa Fe Railway.—The accompanying north and south section and profile from Gainesville, Tex., to Guthrie, Okla., gives at least an idea of the sequence and foldings of the Arbuckle region. Proceeding southward along the line of the Atchison, Topeka and Santa Fe, the typical gypsiferous red beds of Texas, Kansas, Indian Territory, and New Mexico—the alleged Triassic—are see from Guthrie to Oklahoma City, lying in a disturbed but comparatively subhorizontal position, showing greater dips than the Cretaceous, but none of the complicated folding of the Paleozoic strata. South of the Canadian the Carboniferous clays and sandstones appear with the excessive dips of the Ouachita folds. At Buckhorn Creek, east of Dougherty, the coal-bearing beds of the Carboniferous are seen dipping north at an angle of 65° and involved in the folds of the adjacent limestone hills. In this vicinity there are terranes at the base of the Carboniferous, the age of which I could not determine, especially a great thickness of soft sandstone, but the succeeding limestones are undoubtedly a part of the Silurian system.

Proceeding southward from Dougherty to Berwin the limestones, shales, and sandstones of the Precarboniferous succeed each other, but so complicated is the vertical folding that the writer must confess his utter inability to determine their proper succession, even after considerable study. These rocks occupy in cross section almost invariably a subperpendicular position for a distance of 12 miles. From north to south, however, the following distinct subdivisions are apparents.

Continuing southward along our section the mountains cease coincident with the limestones, and after a mile of black shales (No. 7) the well defined Carboniferous sands and shales begin near Berwyn and continue for 29 miles along the railroad to the vicinity of Overbrook. These all occur in vertical folds, apparently coincident with or at least a part of the same system to which the Silurian limestones belong, but which, owing to their disintegrating character, have been leveled down to a low undulating plain. Ten miles south of Ardmore the Trinity sands, the base of the Comanche series, rest unconformably against the Carboniferous (the Red Beds being absent), and upon these in turn to the southward the subhorizontal beds of the Lower Cretaceous.

A parallel north and south section 20 miles west of the Santa Fe road shows the presence of the Red Beds and the absence of the Cretaceous, the latter having deflected southward through Texas.

It is not alone in the mountains of the Paleozoic areas, however, that this remarkable vertical structure is seen, but much of the Carboniferous prairie regions east of the Red Beds are based upon it. For 20 miles north from the Red Bird to the Arbuckle Mountains the undulating prairies, void of any high relief whatever, except

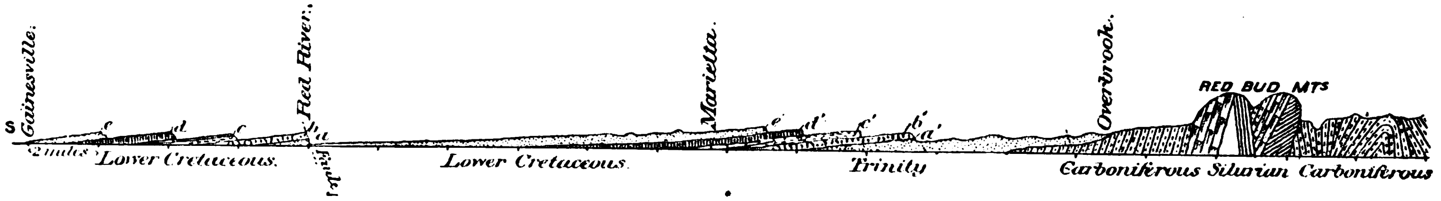

FIG. 12.

SECTION OF INDIAN TERRITORY SHOWING RELATIONS OF STRATA TO ARTESIAN WELLS.

The mountain rocks are too vertical to be of value, while the gently inclined plains present ideal conditions for securing artesian wells north of Red River, the receiving area being the sands outcropping in the valley of stratification at *a*. Water beds: Dakota sands, *e*; Trinity, *a*.

slight rises where the sandstones prevail, are based upon the almost vertical Carboniferous shales and sands, as shown in our diagrams.

The Wichita Division.—The Arbuckle folds west of Duncan are buried beneath the Red Beds for some 30 miles, but outcrop again some 8 miles north of Fort Sill, marking the northern margin of the Wichita Mountains, forming a low foothill which is comparatively inconspicuous, owing to the overshadowing height and sharpness of the adjacent eruptives of the Wichita Mountains proper.

These mountains rise abruptly above the level of the Red Bed prairies, which surround them on every side, and their sharp, jagged outlines present striking and exquisite scenery. The ragged peaks of igneous rock present a strong contrast to the stratified ridges of the eastern and central divisions of the system. Although in Arkansas the latter have a similar elevation above the surrounding plain, they have not the rugged peaks and points of the Wichitas, and are covered by forests. Their aspect is Appalachian; the arid Wichitas remind us of the Rockies; the eastern Ouachitas are the eroded remnants of stratified rocks with their characteristic topography; the Wichitas consist of igneous rocks, hard, firm, ragged, and barren.

These mountains extend westward from Fort Sill 120 miles to the one-hundredth meridian and were partially mapped out by Marcy and McClelland years ago,* and T. B. Comstock has recently made an interesting reconnoissance of them.† The most prominent of the many peaks are Mount Scott and Mount Sheridan; the former is 2,004 feet above sea level, 1,280 feet above Fort Sill on the plain below, and 1,700 feet above Red River, 50 miles distant. Though neither high nor extensive, the Wichitas are models of topography and mountain structure. Mount Scott is a solid mass of red feldspathic granite with little quartz, while neighboring mountains are composed of green stones, basalts, etc., indicating two widely different types of igneous rocks.

The westward continuation of these mountains is buried beneath the Tertiary sediments of the Staked Plains and with it the history of the relation of the Ouachita system to the Rocky Mountains. At one or two places in No Mans Land and north of Clarendon, Tex., I am told that erosion has cut down to the rocks of this mountain system, but I have not been able to find the localities.

The composition of the Wichitas is unlike that of any mountain area of the southwest, and, so far as I could see, presents no structural resemblance either to the basin-surrounded mountains of the Trans-Pecos or the early Paleozoic buttes and denuded folds of the central Texas region. Their age is not determined. They are certainly Post-Silurian and the Red Beds have in part participated in the movements, but the eruptives may be Post-Cretaceous, or even later. The apparent absence of the Lower and Upper Cretaceous in the composition of the Wichitas is especially noticeable. Their trend and composition plainly place them in the Ouachita system.

The country in general is well watered with streams and springs, and nearly everywhere that experiments have been made surface wells have been obtained. I have heard of only one artesian well experiment, and this was at Fort Reno, but no results had been secured at the time of my visit, a year ago.

The topographic conditions favorable for artesian possibilities are found in the high river divides forming the western end of the Ardmore-Wichita mountain system, which crosses the southern third of the Territory, and the high drainage divide of the Cimarron and South Canadian rivers, which is from 200 to 350 feet higher than those streams, and along the crest of which flows the North Canadian, which could be easily diverted down either slope for irrigating purposes.

These two divides or ridges form elevated receiving areas, which, other conditions being favorable, would afford a bountiful artesian supply in the lower valleys of the Cimarron, the South Canadian, the Washita, and Red rivers. The stratigraphic conditions are more difficult to determine, however, owing to the unconsolidated nature of the strata, but as far as ascertained they were favorable as seen in profile, north and south across the State.

Except the Wichita-Arbuckle mountainous axis, forming the divide of the Red and Washita drainage, the rocks are nearly all composed of sands and clays of Red Beds. Whether they present a favorable alternation of porosity and imperviousness for the transmission of the surface rainfall beneath the valleys of the streams mentioned, however, can not be positively stated.

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* See Exploration of Red River of Louisiana, Marcy.

† See First (Second) Annual Report of the Texas State Geological Survey, Austin, 1889.

Between the ninety-seventh and one hundredth meridians there are very favorable conditions for securing artesian water in these valleys, and the experiment should be tried at Guthrie, Kingfisher, Minco, Anardarbo and Henrietta, Texas, where there is a possibility of obtaining artesian water from a purer source beneath the saline and gypsum beds, and where extensive irrigation could be conducted should water be obtained.

The Valley of Upper Red River.—The valley of Red River north of Henrietta and perhaps a portion of the adjacent uplands in Clay, Wichita, Wilbarger, and Hardeman counties, which lie in a synclinial valley, are some 400 feet lower in altitude than the receiving strata of the sloping plains which begins at the Wichita Mountains to the north and some 200 feet lower than the axis of Carboniferous hills to south, present an interesting field for artesian investigation and present favorable conditions, provided the prevalent Red beds formation is sufficiently pervious for the transmission of water.

The Dakota sands in Indian Territory.—No more ideal conditions for magnificent but as yet undeveloped artesian supply could exist than those presented by the Dakota sands in the southern edge of Red River Valley in the Chickasaw Nation east of Washita River.

The Dakota or Lower Cross Timber sands outcrop in the highest divide between the Red River and Washita, and incline at the rate of 100 feet per mile towards Red River. The sands occur as a narrow belt (3 miles wide) of timbered land beginning at the Washita River and running due east to the Blue and from the Blue to the Boggy. This ribbon is about 3 miles south of old Fort Washita and 30 miles north of Denison, from which city it can be seen as the highest visible land in Indian Territory. North of the sands is the narrow parallel strip of Washita prairie, (here known as the 7-mile prairie). South of the timber is the sandy clay, dip plane prairie, underlaid by the Eagle Ford shales, known as the Carriage Point prairie. The inclination of the strata and topography here are such that in my mind, although a drill has never been sunk, abundant artesian water can be obtained from the Dakota sands in Red River Valley, anywhere due north of and opposite Grayson County, Tex., and south of the Territory Cross Timbers at a comparatively shallow depth and if driven deeper, a better supply from the Trinity (Paluxy) sands.

A discussion of the limestone springs of the Arbuckle Mountains will also be found in the chapter entitled Water Conditions of the Hard Limestone Regions.

THE WATERS OF THE HARD LIMESTONE REGION.

The underground streams of limestone regions often attain large proportions, and flow many thousand gallons of water, such as the streams of Nickajack and Mammoth Cave, Ky.

But these streams are the collected underground drainage representing in their volume the water of immense area; and if the reader will only consider the relative area occupied by stream water to that occupied by rock, as shown in caverns, he will see that the chances of the artesian drill from above would be very small for striking this stream, and if struck that there is absolutely no pressure to cause it to rise.

Perhaps the most remarkable and abundant supply of water in the arid region, however, is that found in the eastern slope of the Guadalupe Mountains of southern New Mexico and the Davis Mountains of Texas, and which drains into the Pecos River, affording the chief water supply for the magnificent irrigation development of the Pecos Valley.

This region has been little reconnoitered scientifically and the outlines of the mountain system not even delineated, and with the exception of a valuable report by Dr. G. G. Shumard nothing has been published concerning it.

The Guadalupe mountain area occupies about one thousand square miles in southern New Mexico and adjacent Texas, west of the Pecos and between the thirty-second and thirty-fourth degrees of latitude.

It is made up mostly of hard blue soluble limestone of Permian and earlier Paleozoic rocks, accompanied by some eruptives and granites and sedimentary rocks of later age may be present.

The limestones which compose its greater mass, however, are jointed, thinly stratified, and slightly inclined, affording every opportunity for the collection and transmission of the rainfall which the area receives. In addition, the central peaks and axes are snow covered for a greater portion of the year. Overlying the limestone and at its contact with the Red beds which surround the base of the system, there is an immense stratum of coarse loosely cemented conglomerate composed of the débris of the limestone which forms a magnificent medium for retarded transmission of water. Resulting from these conditions of structure are innumerable springs and streams of superb volume. The whole of the brief time allotted to study the vast region embraced within this report could have been profitably spent in the Guadalupe region alone, but only a short time was allowable for its study. In view of the conditions, however, the writer would advise artesian experimentation in the Tertiary formations surrounding the Guadalupes at lower altitudes than the mountain rocks located relative to it, such as Toyah, Pecos, and Roswell and where the water is apt to be stored by underground reception from contact with the underlying limestone. The volume of these streams according to measurement of Col. Nettleton is given in his report and they constitute the chief volume of the Pecos River, that stream not receiving hardly a drop of water between them and its mouth 400 miles distant.

In addition to the streams there are numerous springs of great volume, which rise through the Red beds and in the river, along the eastern margin of the mountain area, such as shown in the river near Eddy, and at the Chisholm ranch and other points near Roswell.

This superb volume of underground water has created an impression that at most points in the Pecos Valley east of these mountains artesian water can be obtained, but the writer must confess that the truth or falsity of this hypothesis can only be determined by further experimentation. That the later formations of the valley plains surrounding the mountains receive a great deal of this water which does not reach the surface by springs is very evident, and as seen in the wells at Roswell, Toyah, and Pecos City, all of which are just without mountainous area, but not one of which has penetrated to the mountain rock or Red beds. So far as I have been able to ascertain the Pope experimental well, sunk in 1858 about 8 miles east of the Pecos, reached the mountain structure and proved waterless, confirming the theoretical conclusions that massive limestones are not reliable artesian media.

The disposition of the immense amount of water pouring down the cavernous limestones can not all be superficial, however, but much of it must find its way into the overlying clays and gypsums of the Red beds. The Pecos River flows near the contact of the newer formations and the mountain rocks of the Guadalupe (see map) where the river has cut down to the limestone, as at Eddy, N. Mex., the springs burst out of the limestone immediately at the river. Where the Red beds overlying the limestone as between Seven Rivers and Roswell the springs appear as "Johnny holes," *i. e.*, sink holes which sometimes overflow in large streams, as at Chisholm ranche, or may merely fill the "crater," as they are called.

There can be no doubt that these lake springs have their source in the water of the underlying limestones which forces its way up through the gypsum and produces sink holes just as they are produced in hard limestone regions.

These holes are among the most interesting phenomena of New Mexico, occurring as they do in the midst of the Red bed prairies away from water courses and in the most unexpected places.

They are often of great diameter and filled with beautiful water, often of a dark or greenish color and overflowing their lowest edge into a beautiful stream which runs off a few yards or miles to the Pecos River. Large farms are irrigated from these streams, for the particulars of which the reader is referred to Col. Nettleton's report. They occur only in the valley of the Pecos, in New Mexico and Texas. The principal ones are as follows, as given by Mr. Roessler:

> As indicated on the blanks, I could give you no idea of number and extent of springs nor the flow of water from them in the space there allotted.
>
> I will first mention artesian wells. Many have been contemplated, and but one has been attempted, and that of Mr. L. M. Long, work on which has been suspended on account of accident to machinery.
>
> Take the rivers and springs in rotation as they are important in magnitude:
>
> *Rio Pecos.*—As you know, this river traverses ranges 25 and 26 east, north of the second correction line, and also south of that line for a distance of about 20 miles, when the bend runs into range 27 east occasionally, but the principal portion of the river is embraced in range 26, as far south as township 19 south, when it bears east and traverses ranges 26, 27, 28, and near line of Texas, 29 east.
>
> *Rio Hindo.*—This river is formed by the confluence of Rio Bonoto and Rio Ruidoso, in township 11 south, range 18 east, and running east confines itself to townships 10 and 11, and discharges into Rio Pecos.
>
> *North Spring River.*—This stream rises in section 36, township 10 south, of range 23 east, from monstrous springs. Twenty yards from the head this stream is fully 40 feet wide and averages that for a distance of about 4 miles running eastwardly, where it empties into the Rio Hondo, in section 34, township 10, range 24 east. There are two slight falls in the course of this river. It runs smoothly, without any rush. The water is limestone, with an almost imperceptible tinge of gypsum. It is clear and limpid, with a depth of 2 to 4 feet. No watershed, and it has never varied (rising or falling) 1 inch within the memory of the oldest citizens. There are no rocks of importance at its head or along its banks. The volume of water is increased along its route or along its banks. The volume of water is increased along its route by several valuable springs.
>
> *South Spring River.*—This river rises in section 22, township 11 south, of range 24 east. The description of North Spring River will apply to South Spring River, except that it is deeper, not so broad, the water runs much swifter, clear, same class of water, no rocks, carries about the same volume, no important rise or fall, is about 5 miles long, runs north of east, and empties into the Rio Hondo in section 9, township 11, range 25, 700 yards from the Rio Pecos.
>
> *Middle Bernando River.*—This river rises in section 5, township 10 south, range 24 east, from springs. It is about one-half the size of North Spring River, runs more rapidly, same class of water, few rocks, very seldom rises, always full supply, forms confluence with the North Bernando Spring in section 14, and South Bernando River in section 22, township 10, range 24, empties into Rio Hondo in section 25, township 10, range 24.
>
> *North Bernando River.*—This spring is in section 11, township 10, range 24. It supplies water to irrigate two good farms and swells the Middle Bernando River in section 14. Length of stream about 500 yards.
>
> *South Bernando Spring.*—Rises in section 17, township 10, range 24 east, from

springs. Carries nearly as much water as the North Bernando; same class. Description of latter named will describe this. The above three Bernandos deposit their waters in the Rio Hondo.

Bitter Creek and Springs.—This creek comes from a lake in section 9, township 10 south, of range 25 east. This lake is fed from subterranean sources. The valley abounds in springs, and they feed this creek along its source. There is another (nameless) creek which runs into the Rio Pecos a (distance of about 400 yards) in section 15. This (Bitter) creek is about 3 miles long and empties into the Rio Pecos in section 28, township 10 south, 25 range east. Water strongly alkali. Sufficient water for a half dozen farms; three in operation.

Seven-Mile Spring.—This is 7 miles south of the mouth of Rio Hondo. A continuation of very free springs, capable of supplying water for three or four farms. It rises in section 13, township 12 south, of range 25 east, and runs into the Rio Pecos in section 20, township 12 south, of range 25 east. Empties into Rio Pecos in section 33, township 12 south, range 26 east. Splendid water; no rocks.

Nine-Mile Spring.—Nine miles south of Rio Hondo. Rises in section 31, township 12 south, of range 26. Empties into Rio Pecos, in section 33, township 12 south, range 26 east. Facsimile of Seven-Mile Spring.

Rio Feliz.—This stream empties into Rio Pecos in section 35, township 13, range 26. It rises in the mountains more than 50 miles west of the Pecos, runs a fine stream of water for 4 or 5 miles, sinks and rises again a considerable stream within 3 or 4 miles of the Pecos. Fine waters, 25 feet broad (in pools), 3 miles from Pecos. Subject to sudden freshets from its head.

Rio Penasco.—Rises in the mountains 68 miles west of the Pecos, runs 8 miles, sinks, rises again in section 18, township 18, south of range 26 east. Plenty of water at head; size and class of South Spring River. However, acequias have been taken out at the sinks, and it is said that cattle have trodden it down so that water runs some 30 miles in old bed. The land is being rapidly located.

I have taken you down the Rio Pecos some 50 miles, and have left out many springs and living lakes. I could go on to Seven Rivers, Rocky Arroyo, Black River, Delaware River, Grape Springs, and various minor streams, springs, and lakes. The water sinks in several of them, but often rises again. One branch of Seven Rivers runs under a mountain and disappears. The banks of the Rio Pecos are studded with excellent springs. One spring (although on both sides of the Pecos) yields more water than the supply of the city of Denver.

South of the Texas-New Mexican border the basin formation again approaches the mountains, and the Pecos River flows over it for a distance of about 75 miles. The water from the mountain rocks is probably imbibed when it reaches this softer and more unconsolidated formation, and is tapped by artesian wells at Pecos City and Toyah.

A third and remarkable illustration of the occurrence of the water in the massive limestones of the arid regions is found in northern New Mexico, near the Villa de Musquez de Santa Rosa, where magnificent springs of great volume flow from the limestone foothills of the Sierra de Santa Rosa. These springs furnish the beautiful body of water which flows down the Rio de Sabinas and afford a sufficient quantity for irrigation to support an agricultural population of 50,000 people in a region which would otherwise be a total desert.

It is an interesting fact to note that these hard limestones of the Sierra de Santa Rosa are simply the metamorphosed chalks of the Texas region (Comanche series).

The limestone springs of this formation in the Indian Territory, while not attaining the size of those of other regions mentioned are nevertheless numerous and abundant, furnishing a large volume of water which drains off southward into the Red River, that stream having hardly a tributary on its south side worthy of mention east of the Wichita, the drainage from almost its very banks flowing southward into the Trinity. The main limestone springs of the Indian Territory are near Fort Sill, at Cache Creek, near Old Fort Arbuckle, at Woodford and around Wild House, Caddo, and the Washita.

The limestone springs of central Texas.—In the counties of Lampasas and San Saba erosion of the Colorado San Saba and Llano drainage has cut through the chalky and softer Comanche strata to the hard limestones of the Carboniferous and Silurian strata from which magnificent springs flow in great volume. These springs, especially those at Lampasas, are among the lowest and most beautiful natural phenomena in our country and worthy of every traveler's attention.

They burst out of the limestone fissures in such volume that large streams flow from them, which are utilized for extensive water power. They are well described in Mr. Roessler's statistical paper.*

In conclusion, I need only say that in the foregoing pages I have only outlined for the Southwest the underlying principles of the water question as known to-day. Many details have been necessarily omitted, and many of the areas discussed have been only partially reconnoitered, and with the exception of the eastern part none thoroughly explored.

The question of the application of this water to irrigation is left entirely to the irrigation engineers, and to the special agent in charge of the reports, of whom most valuable practical information may be obtained.

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* Letter from the Secretary of Agriculture, transmitting a report on the preliminary investigation to determine the proper location of artesian wells within the area of the ninety-seventh meridian and east of the foothills of the Rocky Mountains, August 21, 1890; R. J. Hinton, special agent in charge. Senate Ex. Doc. No. 222, Fifty-first Congress, first session; Report of F. E. Roesler, C. E. division, field agent for Texas, pp. 243–319.

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